Buyers of First Resort: Guaranteed Public Demand and Corporate Scientific Research*

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Abstract

Firms invest in scientific research to increase their chances of landing guaranteed public demand. Using data on $5.9 trillion in U.S. government procurement contracts matched to 4,520 publicly traded U.S. firms during 1980-2015, we estimate the effect of R&D contracts on upstream and downstream corporate R&D (measured by scientific publications and patents, respectively). Identification is based on firm-specific exposure to changes in (i) industry-level procurement funding, (ii) agency-level windfall funding resulting from the congressional appropriations process, and (iii) federal procurement priorities after the end of the Cold War. We document a positive effect of R&D contracts on publications. Moreover, we show that the effect is stronger for larger firms, and when private market incentives to perform risky research are weak. R&D contracts encourage publications that (i) are not used in the firm's internal inventions, (ii) spill over to rivals' inventions, and (iii) are not protected by patents. We also show that the effect has weakened over time as the U.S. government has increasingly procured commercially proven technologies. Decoupling R&D contracts from product procurement may have had adverse implications for corporate incentives, potentially contributing to the withdrawal of corporations from performing scientific research.

1 Introduction

Between 1980 and 2015, American businesses funded $1.7 trillion in basic and applied research, which accounted for 45% of all scientific research performed in the United States.[1]

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[1]Data are from Tables 2, 3, and 4 of the National Patterns of R&D Resources series published by the National Science Foundation (National Center for Science and Engineering Statistics, 2019). All dollar amounts in this paper are reported in constant 2012 dollars.

By lowering the cost of research and increasing its private value, the U.S. government plays an important role in encouraging corporations to participate in upstream R&D. The government affects cost directly, using subsidies and grants (Bloom, Griffith, & Van Reenen, 2002; Fleming, Greene, Li, Marx, & Yao, 2019; Wallsten, 2000), and indirectly, via spillovers from government-funded research performed in federal laboratories and universities (Adams, Chiang, & Jensen, 2003; Cohen, Nelson, & Walsh, 2002; Goolsbee, 1998; Jaffe & Lerner, 2001; National Academies of Sciences, Engineering, and Medicine, 2021). At the same time, government procurement contracts can increase the private value of upstream R&D through guaranteed public demand.[2] This channel is particularly effective at driving corporate research when private market incentives are insufficient, as is the case when commercial applications lie in the future (Weiss, 2014), knowledge spills over to rivals (Arora, Belenzon, & Sheer, 2021; Bloom, Schankerman, & Van Reenen, 2013), and incomplete contracts and asymmetric information make markets for technology inefficient (Arora, Fosfuri, & Gambardella, 2001; Arrow, 1962; Edler & Georghiou, 2007; Kremer, Levin, & Snyder, 2020). In this paper, we document the government's role in de-risking corporate research by guaranteeing public demand, and explore how this role has changed over time.

The development of lasers exemplifies how government procurement can drive corporate research by filling voids in private demand. The Air Force Office of Scientific Research, the Advanced Research Projects Agency, and the Army Signal Corps all funded competing research teams in the R&D race to build the first laser. Military contractor Hughes Research Laboratories demonstrated the ruby laser on May 16, 1960. The demonstration was duplicated at Technical Research Group Inc. and AT&T's Bell Labs shortly thereafter. Yet, it took many years for private laser markets to develop. Throughout the 1960s, government agencies acted as *buyers of first resort*: procurement contracts for measurement and optical communication lasers enabled corporate research laboratories to scale and improve the technology. By 1969, the Department of Defense's share of the laser market was 63.4% (Bromberg, 1991). In the early 1970s, growth in military laser procurement slowed, universities curtailed their laser purchases, and companies redirected their R&D toward civilian applications that held promise for short-term payoffs. Commercial applications in communications, measurement, cutting, and welding emerged. In the 1980s, lasers became prominent in the consumer economy as supermarket scanners, printers, and optical discs (Hecht, 2010). There is little doubt that the development of the commercial laser industry was enabled by government demand during the technology's early years.[3]

[2] The government also affects corporate R&D by designing patent policies, enforcing antitrust laws, and setting regulations (e.g., Aschhoff & Sofka, 2009; Bloom, Van Reenen, & Williams, 2019; Cunningham, Ederer, & Ma, 2021; Jaffe, Newell, & Stavins, 2003), mechanisms that are outside the scope of this paper.

[3] Mowery (1998) makes a similar case for commercial aerospace, semiconductors, computers, and software.

In fiscal year 2015, the U.S. government awarded businesses $440 billion in procurement contracts, which included $39 billion for R&D services (USAspending.gov, 2021b). It awarded just $4 billion in grants to businesses.[4] Despite their large size, we know relatively little about the effect of procurement contracts on corporate R&D, or how the effect operates. Most prior studies examine the public funding mechanism by focusing on (i) grants from the Small Business Innovation Research program and the National Institutes of Health (e.g., Audretsch, Link, & Scott, 2002; Azoulay, Graff Zivin, Li, & Sampat, 2019; Howell, 2017; Lerner, 1999; Wallsten, 2000) and (ii) spillovers from federal laboratories (e.g., Adams et al., 2003; Jaffe & Lerner, 2001; Link & Scott, 2020; Link, Siegel, & Van Fleet, 2011; Mowery & Ziedonis, 2001) or universities (e.g., Cohen et al., 2002; Tartari & Stern, 2021). Procurement contracts are the focus of only a handful of studies (e.g., Barder, Kremer, & Levine, 2005; Howell, Rathje, Van Reenen, & Wong, 2021; Lichtenberg, 1988; Moretti, Steinwender, & Van Reenen, 2021; Slavtchev & Wiederhold, 2016). However, none of these studies distinguish between upstream and downstream corporate R&D. This distinction is important because weak private market incentives should be especially relevant for scientific research, for two reasons. First, by its very nature, upstream R&D is further from the market. Therefore, private demand may be missing, insufficient, or lie further into the future. Second, private obsolescence and appropriability concerns are more severe for upstream R&D due to knowledge spillovers and weak patent protection. Government procurement contracts can mitigate these concerns by creating exclusive public markets through guaranteed demand.

An important contribution of this paper is distinguishing between scientific research ("R") and downstream development ("D") in corporate R&D. Yet, a clear distinction is difficult to draw, both conceptually and empirically. Science is a systematic enterprise directed toward a better understanding of the universe, while technology is the application of knowledge for practical purposes (Nelson, 1996). The main difference between scientific and technical knowledge is that the former is concerned with general laws, while the latter explains how and why specific artifacts work. Because both scientific and technical knowledge ultimately advance understanding, this distinction is a matter of degree, rather than a stark dichotomy. Empirically, using publications to measure scientific research and patents to measure technology development presents some challenges as well. Advances in technology can find their way into publications, and scientific knowledge can sometimes be patented

[4] It is important to distinguish between R&D contracts and grants (David, Hall, & Toole, 2000). Under a contract, the contractor provides services to the government for a fee. Under a grant—a form of financial assistance—the government transfers something of value (either money or in kind) to the grantee so the grantee can carry out activities to benefit the public (Datalab, 2018). The economic mechanisms behind contracts and grants are also different. While grants are typically used to lower the cost of R&D, contracts are used as a "ticket" to gain access to lucrative downstream product contracts (Lichtenberg, 1988). To address these differences, we control for grants in our analyses of R&D contracts.

(Murray & Stern, 2007). Yet, our premise is that research output appears in the scientific literature disproportionately more than technology development does.[5]

With these caveats in mind, we estimate the effect of government procurement contracts on corporate R&D expenditures, publications, and patents. We enhance the panel of 4,520 firms and 60,885 firm-year observations from Arora et al. (2021) by adding data on $5.9 trillion in procurement contracts and $19.2 billion in grants awarded by dozens of federal agencies. We measure firms' contracting activities using the value of contracts awarded, upstream R&D using publications authored by corporate scientists, and downstream R&D using patents assigned to the firms. We focus on R&D contracts because they give winning firms access to guaranteed public demand. In our sample, 78% of firms that win an R&D contract subsequently receive at least one noncompetitive product contract. Among firms that never win an R&D contract, only 32% receive at least one noncompetitive product contract. We also explore temporal changes in the composition of government procurement. Sweeping policies implemented in the 1980s and 1990s shifted the composition of contracts *away from* mission-focused technologies that met unique government specifications (which accounted for the majority of procurement dollars in the 1960s and 1970s) and *toward* commercial items and dual-use technologies (Weiss, 2014).[6] Arguably, this reorientation toward commercially proven technologies reduced the government's ability to de-risk corporate scientific research.

We present two sets of findings. First, we document a positive effect of R&D contracts on corporate publications, but not on corporate patents. Potential explanations for not finding an effect on patents include: (i) guaranteed public demand may reduce the need to exclude rivals through patenting; (ii) the government may restrict patenting due to disclosure concerns; and (iii) private market incentives are likely to be stronger for technology development, rendering guaranteed public demand less effective. We explore the mechanism behind the effect of R&D contracts on publications. Guaranteed public demand should drive corporate scientific research when capturing returns in private markets is difficult. Consistent with this argument, we find a larger effect of R&D contracts on publications that are (i) not cited by the firm's own patents (missing downstream applications), (ii) cited by rival firms' patents (indicating a strong market-stealing effect due to spillovers to product-market competitors), and (iii) not protected by the firm's own patents. In addition, we find a stronger effect for larger firms, which are less resource-constrained. This result is consistent with manufacturing capabilities and complementary assets being necessary to execute large-scale product contracts.

[5] Arora et al. (2021) validate this premise using the Carnegie Mellon Survey of R&D-performing firms.

[6] Dual-use technologies can be used in both military and commercial applications (Code of Federal Regulations, 2000).

A major empirical challenge is how to deal with the endogeneity of contracts (David et al., 2000). Common shocks can affect both corporate R&D and government procurement.[7] We implement two strategies to mitigate this concern. First, we use variation in aggregate, industry- and agency-level funding to predict firm-level contracts. Our identifying assumptions are that (i) aggregate changes in funding are unrelated to a firm's idiosyncratic shock in the innovation equations, and (ii) a firm's exposure to these changes is predetermined. Second, we exploit a quasi-natural experiment, the end of the Cold War, that triggered substantial reallocation in government contracts due to changes in national priorities, rather than technology or demand shocks. Our causal estimates point to a positive effect of R&D contracts on publications, but not on patents. The causal estimates are larger than the OLS estimates, suggesting that contracts target firms experiencing negative shocks. This finding is consistent with government procurement aiming to maintain the existing military-industrial base (Peters, 2021).

Second, we show that the effect on publications was stronger before the policy reforms of the 1980s and 1990s changed the composition of government procurement. By dollar value, the share of R&D contracts in all contracts fell from a high of 29% in 1994 to 10% in 2015 (see the solid line in Figure 1). Within-firm estimates suggest this drop was not driven by decreases in R&D contracts awarded to traditional contractors, but rather by entry from nontraditional contractors.[8] We interpret this to mean that winning R&D races became less important for downstream procurement. At the same time, the share of commercial contract dollars in all contracts increased from 0% in 1994 to 14% in 2015 (see the dashed line in Figure 1).[9] These temporal changes occurred across a wide range of industries (see Appendix Figure H3).

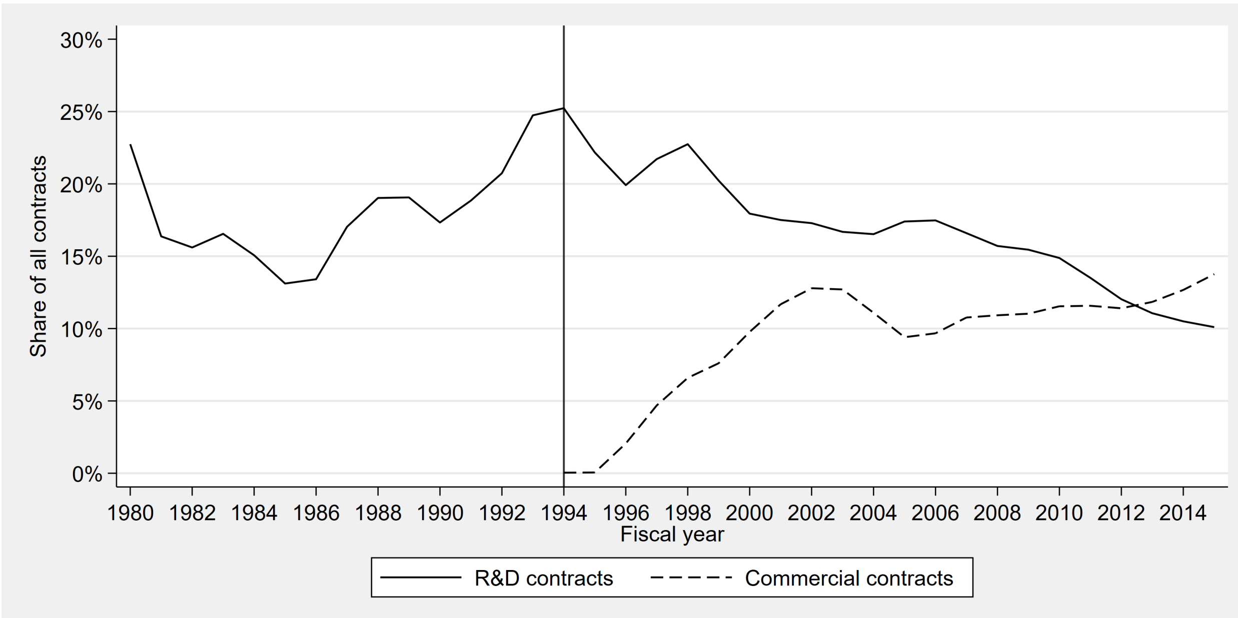
Winning large procurement contracts no longer requires scientific capabilities. Figure 2 shows that the average contract value per $1 million in firm sales has remained relatively stable for firms that publish scientific publications (solid line), but has increased sharply for firms that never publish scientific publications, from less than $2,000 in 1980 to $51,000 in 2015 (dashed line). Concurrently, the number of corporate publications per $1 million in research contracts has declined from a high of 8 in 1983 to less than 2 in 2015 (shaded area). Arora, Belenzon, and Patacconi (2018) document a decline in the stock market value and the mergers and acquisitions (M&A) value of scientific capabilities. We show that corporate

[7]If contracts target firms that experience positive technology or demand shocks, then OLS estimates are upward-biased. If they target firms that experience negative shocks, then OLS estimates are downward-biased.

[8]Attracting nontraditional contractors, such as firms operating in the large commercial IT markets, was one of the government's explicit policy goals.

[9]Commercial contracts are awarded using streamlined acquisition procedures that are designed to resemble transactions in commercial markets.

Figure 1: Share of R&D Contracts in All Contracts Over Time



Notes: This figure plots the share of R&D contract dollars in all contracts awarded by the federal government to our sample of firms over time (solid line). The share of commercial contract dollars in all contracts is presented from 1994 (the first year when the classification became available) through 2015 (dashed line). Commercial contracts use special (usually simplified) requirements that are designed to resemble transactions in commercial markets.

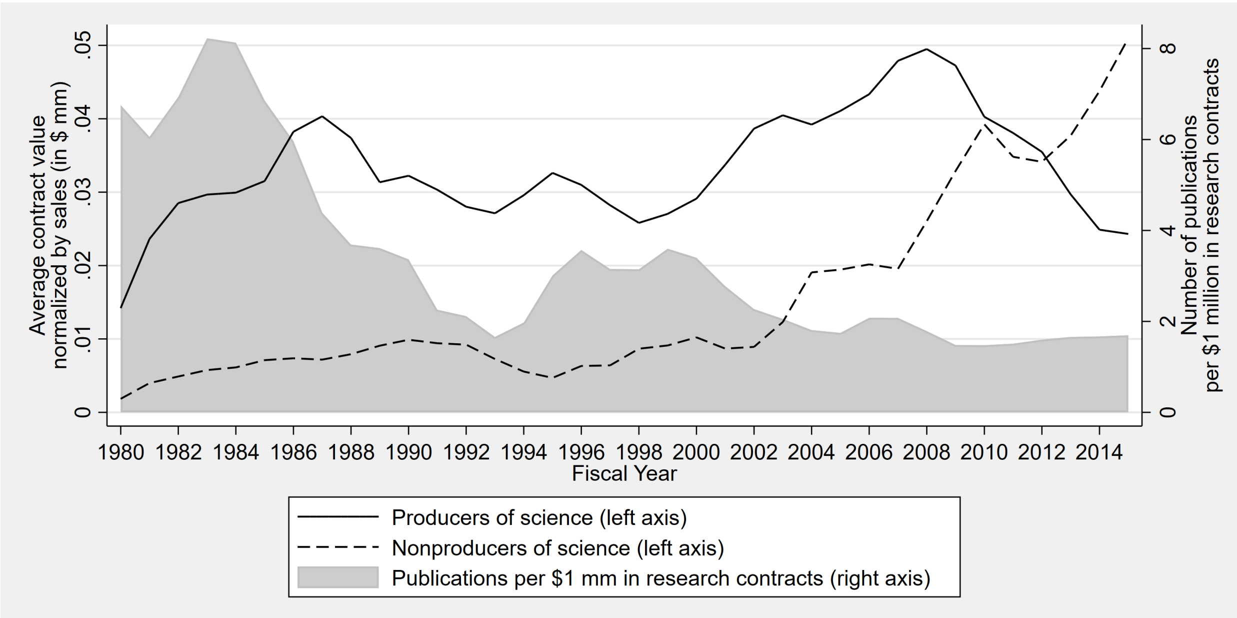
scientific capabilities have fallen out of favor with the U.S. government as well.

Our final examination focuses on temporal changes in the relationship between winning R&D contracts and guaranteed public demand. The government has historically awarded a majority of procurement contracts noncompetitively, providing guaranteed demand to firms that demonstrated strong technical capabilities.[10] Over time, pressures to reduce cost and increase efficiency and transparency have led to legislative mandates to use competition whenever practicable (Manuel, 2011). Figure 3 shows that the share of competitive contracts in all contracts (by dollar value) has increased from 36% in 1980 to 68% in 2015. Competition has increased even more for service contracts (whether for R&D or other services). At the same time, the share of noncompetitive product contracts (a proxy for guaranteed public demand) has dropped from 78% in 1980 to 49% in 2015. The rise in competitive procurement has limited the government's ability to guarantee public demand. This should hamper corporate research if firms perform upstream R&D as a pathway to subsequent noncompetitive product contracts.

In summary, Figures 1-3 highlight three forces that shape how government contracts

[10]In noncompetitive procurement, the government either selects the company to buy from or restricts the bidding process to certain suppliers.

Figure 2: Average Contract Value Over Time

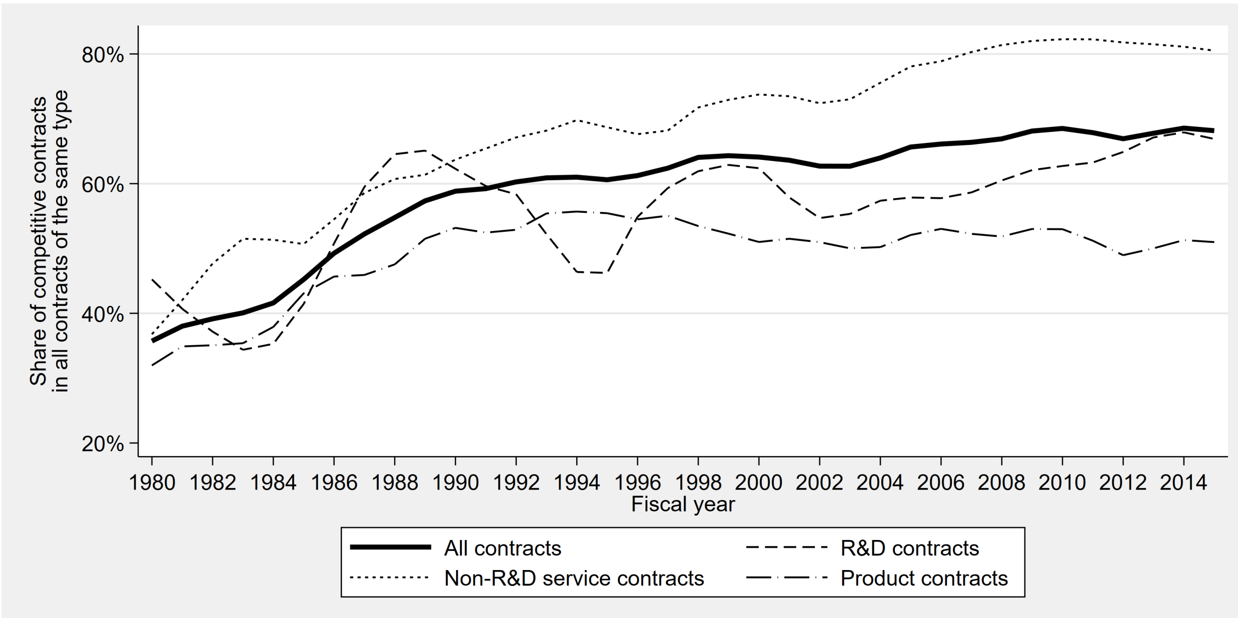


Notes: This figure plots the average contract value awarded to producers and nonproducers of science over time (left axis) and the number of corporate publications per $1 million in research contracts (right axis). We classify a firm as a *producer of science* if its annual number of publications over annual sales is above industry median value. Other firms are classified as *nonproducers of science*. *Average contract value normalized by sales* is the ratio of total contract value and total sales. *Number of publications per $1 million in research contracts* is the ratio of total number of publications to total value of research contracts. Dollar values are adjusted using the GDP Implicit Price Deflator to reflect 2012 dollars (U.S. Bureau of Economic Analysis, 2021).

drive corporate R&D: (i) the rise in the prevalence of commercial contracts, which limits the government's ability to replace missing private demand, (ii) the larger allocation of contracts to firms that do not participate in scientific research, and (iii) the diluted importance of R&D races in securing public demand. These trends may have adverse implications for corporate R&D. To the extent that guaranteed demand is an important reward mechanism, encouraging downstream competition should lower the expected returns to R&D. In addition, contractual problems may mean that downstream procurement is an important component of the reward to upstream R&D investment. Decoupling R&D from production may lead to inefficiencies in project implementation due to tacit knowledge and complementarity between R&D and production, as well as contractual problems making it harder to implement decoupled projects (Che, Iossa, & Rey, 2021). Yet, the increase in procurement from firms with limited scientific capabilities suggests decoupling has become more prevalent, potentially contributing to the withdrawal of corporations from performing scientific research.

The rest of the paper proceeds as follows: Section 2 positions our study in the literature.

Figure 3: Share of Competitive Contracts in All Contracts Over Time



Notes: This figure presents the trend in the share of competitive contract dollars in all contracts of the same type obligated by federal agencies to all recipients (not limited to our sample firms). Competitive contracts are awarded using full and open competition.

Section 3 presents the data, Section 4 outlines the econometric specifications, and Section 5 presents the estimation results. Section 6 concludes and suggests directions for future work.

2 Related Literature

A voluminous literature examines the government's effect on corporate R&D through subsidies (e.g., Bloom et al., 2002), public funding (e.g., Azoulay et al., 2019; Howell, 2017; Howell et al., 2021; Lerner, 1999; Packalen & Bhattacharya, 2020; Wallsten, 2000), and spillovers from federal laboratories and universities (e.g., Adams et al., 2003; Cohen et al., 2002; Fleming et al., 2019; Jaffe, Fogarty, & Banks, 1998; Jaffe & Lerner, 2001; Link & Scott, 2020; Link et al., 2011; Mowery & Ziedonis, 2001). Government procurement has also been the subject of studies looking at optimal contract design (e.g., Arve & Martimort, 2016; Bhattacharya, 2021; Che et al., 2021; Decarolis, 2014), competition in contracting (e.g., Kang & Miller, 2021) and waste/efficiency in contracting (e.g., Bandiera, Prat, & Valletti, 2009; Liebman & Mahoney, 2017). Only a handful of studies empirically examine procurement contracts and, to the best of our knowledge, none of them focus on corporate science or systematically test the guaranteed demand mechanism.

Most existing studies focus on lowering the cost of R&D through subsidies and public funding. For example, small-firm research shows that Small Business Innovation Research (SBIR) grants crowd out firm-financed R&D expenditures (Wallsten, 2000). Yet, early stage SBIR awards also increase forward citation-weighted patents, especially for financially constrained firms (Howell, 2017), and the likelihood of raising venture capital (Lerner, 1999). In a recent paper, Howell et al. (2021) evaluate policy reforms aimed at changing how the U.S. Air Force SBIR program procures innovative technologies from small businesses. They compare the conventional approach to R&D contracting, where firms respond to solicitations for specific research topics, with an open approach that allows firms to submit proposals on any topic. Using data on 7,229 proposals submitted by 3,170 firms during 2017-2019 and a regression discontinuity design, they find that winning an open-topic R&D competition increases the likelihood of raising venture capital funding and improves the chances of winning a subsequent non-SBIR contract from the Department of Defense (DoD). This finding supports the premise that winning R&D races is a pathway to subsequent government contracts.

Large-firm research shows that National Institutes of Health (NIH) grants have a positive effect on corporate R&D (Azoulay et al., 2019). An additional $10 million in NIH grant funding for a research area generates 2.3 additional biopharmaceutical firm patents in that area, or roughly one patent for every 2-3 NIH grants. This result underscores that patents are an effective tool for appropriating returns from corporate R&D in the biopharmaceutical industry. Yet, the NIH's tendency to fund new ideas has declined over time (Packalen & Bhattacharya, 2020). Between the 1990s and the 2000s, grant support shifted from "edge science" toward more traditional science. This coincides with the shift in procurement contracts from mission-focused technologies to commercial items. It suggests that the government's withdrawal from funding risky, explorative science that lays the foundation for subsequent breakthroughs occurred not only in contracts, but also in grants.

Many studies focus on spillovers from government-funded research in federal laboratories and universities to corporate R&D. For example, Mowery and Ziedonis (2001) document the relatively limited role of spinoffs in commercializing laboratory-owned technologies. Jaffe and Lerner (2001) show an increase in patenting of federally owned technologies after 1986, with no overall decrease in citation intensity, which they attribute to laboratories reorienting their research toward areas with greater commercial applicability. They also find that laboratories performing a greater share of basic science have fewer patents and cooperative research and development agreements (CRADAs). These patterns complement the trend in commercial contracts from Figure 1. Adams et al. (2003) find that corporate laboratories that have CRADAs patent more and invest more in R&D expenditures. They also document that CRADAs dominate other channels of technology transfer from federal laboratories to firms.

These patterns point to the importance of formal agreements between firms and government entities.

Only a couple of studies examine procurement contracts and are closely related to this paper. Lichtenberg (1988) investigates the effect of DoD contracts on firm R&D expenditures using a panel of 169 U.S. contractors during 1979-1984. He distinguishes between competitive procurement (contracts awarded using full and open competition) and noncompetitive procurement (contracts exempted from full and open competition; the list of exceptions is included in Appendix C). He uses aggregate product-level contracts to instrument for the contracts awarded to a focal firm. Lichtenberg estimates that a \$1 increase in competitive procurement (including both R&D and non-R&D contracts) increases firm R&D expenditures by \$0.54.[11] He argues that competitive procurement spurs firm-financed R&D because winning contractors are almost guaranteed to receive much larger follow-on noncompetitive contracts. This is a key point that we underscore as well. Conversely, noncompetitive R&D contracts reduce R&D expenditures for both winners (who let the government sponsor the cost of R&D) and losers (who reduce expenditures because the follow-on contracts are no longer at stake). These findings support the view that R&D contracts drive corporate science because they represent a "ticket to play" in the lucrative downstream public market.

Recently, Moretti et al. (2021) study the effect of government-funded R&D on corporate R&D investment and productivity growth using industry data from OECD countries and firm data from France (i.e., 12,539 French firms between 1980 and 2015). They document a "crowding in" effect, whereby increases in government-funded R&D for an industry or firm drive private R&D in that industry or firm.[12] In the firm-level analyses, they use industry-level defense R&D subsidies to instrument for the public R&D funding received by a focal firm. At the mean values of public and private R&D in France, they estimate that a €1 increase in government-funded R&D generates €0.85 of additional corporate R&D. Moreover, they estimate that the induced increases in corporate R&D result in significant labor productivity gains.

Our work diverges from previous studies in several important ways. First, we examine the effect of procurement contracts separately on corporate research ("R") and development ("D"). This matters because the economic mechanism behind the effect—guaranteed demand—should be more relevant for upstream vs. downstream R&D. Indeed, we find an effect of contracts only on scientific research, especially when private market incentives are insufficient. This sheds light on the returns to upstream corporate R&D in the context of

[11]Similarly, we find that a \$1 increase in R&D contracts increases R&D expenditures by \$0.57, while a \$1 increase in competitive procurement raises R&D expenditures by \$0.64.

[12]The authors calculate corporate or privately funded R&D as the difference between the firm's R&D budget and total R&D subsidies, other national funds, and international funds.

public markets. Second, this paper makes progress on data and identification. We extend the work of Lichtenberg (1988) by matching contracts from dozens of agencies to thousands of firms and their subsidiaries over several decades. In terms of identification, both Lichtenberg (1988) and Moretti et al. (2021) use aggregate contract values to predict contracts awarded to a focal firm. We do the same with several instruments, but also present causal evidence that exploits changes in procurement driven by geopolitical, rather than technological, forces. Third, this paper is the first to analyze temporal changes in (i) the composition of government procurement and (ii) the relationship of contracts with firm scientific capabilities. These analyses are important for understanding the implications of procurement policies implemented throughout the 1980s and 1990s.

3 Data

We combine data from three primary sources: (i) corporate R&D data, including matched patents from PATSTAT and academic publications from Web of Science, obtained from Arora et al. (2021); (ii) government procurement contracts data reported to the Federal Procurement Data System (FPDS); and (iii) government grants data reported to the Treasury DATA Act Broker. Our data construction work is detailed in Appendix B.

3.1 R&D Expenditures, Publications, and Patents

We extend the panel from Arora et al. (2021) by matching firms to federal procurement contracts awarded during fiscal years 1980-2015 and grants awarded during fiscal years 2001-2015.[13] Because the firm panel from Arora et al. (2021) accounts for changes in company names and ownership structures over time (e.g., due to mergers, acquisitions, or spinoffs), our data allow us to construct accurate contract and grant flows in a long panel.

Our sample includes 4,520 publicly traded firms headquartered in the U.S. that had (i) at least one year of R&D expenditure data during 1980-2015, (ii) at least one granted patent during 1980-2015, and (iii) at least three years of consecutive records from the first patent. We use data on firm accounting measures (e.g., sales and R&D expenditures sourced from Standard & Poor's Compustat North America), publications (sourced from Clarivate's Web of Science), and patents (sourced from the European Patent Office's PATSTAT database). Similar to Arora et al. (2018) and Arora et al. (2021), we measure firms' upstream R&D using publications authored by their corporate scientists, and downstream R&D using granted

[13] We focus on "prime" contracts and grants awarded to firms that work directly with the government. We do not include subcontracts or sub-grants because they are not consistently available over our sample period.

patents. In addition, we measure firms' contracting by the annual value of procurement contracts. Our variable construction work is detailed in Appendix C.

3.2 Government Contracts

We collect all procurement contracts and indefinite delivery vehicles (IDVs) awarded by all federal agencies from two government websites, SAM.gov for 1980-2000 and USAspending.gov for 2001-2015.[14] We match the names of contract recipients and their parent companies to the names of subsidiaries and their ultimate owners from our firm panel (see Appendix B for details). We identify 2,590 firms that receive a total of $5.9 trillion in procurement contracts from 76 federal agencies during the sample period.[15] Contractors typically receive multiple contracts per year.[16] We aggregate contracts at the firm-year level by summing up all the contracts and modifications awarded to an ultimate owner and its subsidiaries each fiscal year.

The distribution of contracts by awarding agency is highly skewed. The DoD accounts for 69% of all contract dollars awarded during 1980-2015, while the Department of Energy (DoE), National Aeronautics and Space Administration (NASA), General Services Administration (GSA), and Health and Human Services (HHS) account for another 16% (see Appendix Table B1). Moreover, five agencies account for 99% of all R&D contract dollars awarded to our sample firms: DoD (81%); NASA (15%); DoE (1%); HHS (1%); and the Department of Transportation (1%).

Agencies use a four-digit *Product or service code* to describe the principal product or service purchased in each contract.[17] We use this classification system to separate contracts into *R&D contracts* and *non-R&D contracts*. We further divide non-R&D contracts into *non-R&D service contracts* and *product contracts*. In addition, we use crosswalks between product and service codes, the North American Industry Classification System (NAICS), and the Standard Industrial Classification (SIC) to identify the four-digit industry (SIC4)

[14] IDVs are agreements that allow agencies to place supply and service orders. Examples include blanket purchase agreements, government-wide acquisition contracts, and indefinite delivery contracts. As of November 2, 2020, the Federal Procurement Data System recognizes 6,725 active contracting offices subordinated to 99 first-level "departments." For consistency with USAspending.gov, we use the term "agency" to mean either a department or independent agency, commission, or other U.S. government entity.

[15] The government reports *obligations* for procurement contracts and IDVs, not actual *outlays*. An obligation is the government's promise to spend funds (immediately or later) as a result of entering into a contract, so long as the agreed-to actions take place. An outlay takes place when those funds are actually paid out to the contractor (Datalab, 2018). The contracts we match to our panel represent 49% of the $12.5 trillion in procurement contracts awarded by the federal government during 1980-2015.

[16] Appendix A summarizes the typical government procurement process. We identify 8.6 million unique contracts awarded to our sample firms.

[17] See Appendix Tables C4 and C5 for the 24 letter codes used to classify services and 78 two-digit numerical codes used to classify products, respectively.

for each procurement contract. This allows us to calculate the value of procurement contracts for each industry-year, which is essential for constructing our instrumental variables.

The Federal Acquisition Streamlining Act of 1994 establishes a statutory preference for procuring commercial items (Barry, 1995). As a result, agencies acquire products and services as diverse as computers, transportation, and medicine using simplified requirements and streamlined practices intended to resemble those used in commercial markets (e.g., exempting contractors from the requirement to submit certified cost or pricing data). We use the *Commercial items acquisition procedures* field to break down non-R&D contracts into *commercial contracts* and *noncommercial contracts*.[18] This allows us to test the theory that government contracts affect corporate R&D through guaranteed public demand, especially when market incentives are insufficient (e.g., for technologies that do not have existing commercial applications).

3.3 Government Grants

We collect all the financial assistance awards (including grants, cooperative agreements, and direct payments, but not loans or insurance; henceforth "grants") awarded by all federal agencies during fiscal years 2001-2015 from USAspending.gov.[19] We match the names of grantees to our firm panel. We identify 456 U.S.-headquartered firms that receive a total of $19.2 billion in grants from 25 federal agencies during 2001-2015. Similar to contractors, grant recipients typically receive multiple grants per year. We aggregate grants at the firm-year level by summing up all the grants and modifications awarded to an ultimate owner and its subsidiaries each fiscal year. This allows us to control for government funding when we test the guaranteed demand mechanism.

Similar to contracts, the distribution of grants by awarding agency is highly skewed. The DoE accounts for 40% of all grants awarded to sample firms during 2001-2015, followed by the DoD (14%), Department of Agriculture (9%), HHS (9%), and State Department (8%). By dollar value, 55% of awards are cooperative agreements, 33% are block, formula, or project grants, and 12% are direct payments.

3.4 Descriptive Statistics

Table 1 presents descriptive statistics for the main variables used in the econometric analyses. Approximately 70% of firms perform scientific research (i.e., have at least one publication).

[18] We do not break down R&D contracts into commercial and noncommercial because the former would represent less than 1% of the total value of R&D contracts awarded to our sample firms.

[19] We do not include grants for fiscal years 1980-2000 because the data are only available for select agencies (e.g., National Science Foundation and National Institutes of Health).

These firms publish an average of 17 scholarly publications per year (and a median of 1). By construction, all firms have at least one patent. Firms produce an average of 22 patents per year (and a median of 1). Approximately 57% of firms receive at least one contract during 1980-2015 (we refer to these firms as "contractors"), 23% receive at least one R&D contract during 1980-2015, and 10% receive at least one federal grant during 2001-2015.

Table 1: Descriptive Statistics

	(1)	(2)	(3)	(4)	(5)	(6)
				Distribution		
	Obs.	Mean	Std. dev.	10th	50th	90th
R&D expenditures ($ mm)	54,238	111	557	1	10	147
Publications	46,701	17	96	0	1	20
Patents	60,885	22	132	0	1	32
All contracts ($ mm)	41,631	111	1,278	0	0	26
R&D contracts ($ mm)	41,631	18	275	0	0	1
Non-R&D contracts ($ mm)	41,631	93	1,038	0	0	24
Commercial contracts ($ mm)	27,197	13	107	0	0	4
Noncommercial contracts ($ mm)	27,197	93	1,157	0	0	11
All grants ($ mm)	5,495	2	21	0	0	3
Sales ($ mm)	60,557	2,603	12,749	3	146	4,332
R&D stock ($ mm)	60,885	428	2,496	1	26	483

Notes: This table displays descriptive statistics for the main variables used in the econometric analyses. The unit of analysis is a firm-year. Publication and contract statistics are only provided for firms that perform scientific research and contractors, respectively. Commercial and noncommercial contracts are only summarized for fiscal years 1994-2015. Grant statistics are only provided for fiscal years 2001-2015 and firms that receive at least one grant during this period.

In our sample, contractors receive an average of $111.5 million in procurement contracts per year. Of those dollars, an average of $18.1 million are for R&D services, which is almost an order of magnitude higher than the annual grants received by grant recipient firms. On average, contractors receive contracts from 5 federal agencies (with a median of 2 agencies). Consistent with the premise that R&D contracts are the "ticket to play" in the government market, 78% of sample firms that win an R&D contract subsequently receive at least one noncompetitive product contract. Among firms that never win an R&D contract, only 32% receive at least one noncompetitive product contract.

There is substantial heterogeneity in contracts by awarding agency, as shown in Appendix Table E7. For example, the average value of an R&D contract ranges from $8,362 for the Federal Maritime Commission to $12,808,836 for the U.S. Agency for International Development. The average R&D contract from DoD is $4.9 million, while the average R&D contract from NASA is $7.3 million. Typically, product contracts awarded noncompetitively by the

DoD, NASA, DoE, and Department of Homeland Security (DHS) are larger than all product contracts. This suggests that firms may have strong incentives to win R&D contracts from these agencies as pathways to the larger noncompetitive product contracts.[20]

There is some heterogeneity in the characteristics of R&D contractors working for different agencies, as shown in Appendix Table E8. For example, firms that win R&D contracts from the Department of Commerce (DoC) tend to publish more than other R&D contractors. Firms that win large R&D contracts from one agency tend to also win large R&D contracts from other agencies, as shown in Appendix Tables H21 and H22. Regardless of contract size, defense R&D contractors tend to also work for NASA, as shown in Appendix Table H23. In general, if a firm is an R&D contractor for an agency, it is also a defense R&D contractor.[21] This suggests that firms may be able to leverage their competitive advantages across R&D competitions from different agencies.

Our sample is drawn from a wide distribution of industries, as indicated in Appendix Table H25. We classify those industries into several main groups, as shown in Appendix Table H24. The largest average annual R&D contracts are in the Others group ($45 million), while the smallest are in Chemicals ($1 million), as can be seen in Appendix Table F9. Among contractors, the number of publications per $1 million in contracts ranges from a low of 0.05 in the Others group to a high of 4.14 in Chemicals. Industry groups with the lowest and highest numbers of patents per $1 million in contracts are Instruments and Chemicals, respectively. Among R&D contractors, the average number of publications per $1 million in R&D contracts ranges from a low of 0.29 in the Others group to a high of 63.07 in Drugs. Meanwhile, the average number of patents per $1 million in R&D contracts ranges from a low of 0.51 in Instruments to a high of 37.38 in Chemicals. The composition of government contracts varies by main industry and over time, as shown in Appendix Figure H3.

Table 2 presents mean comparison tests between 1,019 R&D contractors and the other 3,501 firms in our sample. On average, R&D contractors are much larger ($6 billion vs. less than $1 billion in annual sales). They invest more in R&D ($264 million vs. $34 million per year), but they have lower R&D intensity ($1.4 million vs. $5.9 million in R&D expenditures per $1 million in sales). In addition, R&D contractors perform more scientific research (0.4 vs. 0.3 annual publications per $1 million in R&D expenditures), and about half as much downstream development (0.6 vs. 1.2 patents per $1 million in R&D

[20] Agencies use full and open competition to award R&D contracts more often that they do to award product contracts. Of the $908 billion in R&D contracts awarded to sample firms during 1980-2015 by all federal agencies, 56% were awarded competitively. Conversely, of the $3.4 trillion in product contracts, only 36% were awarded competitively.

[21] At the high end, 93% of DoC R&D contractors are defense R&D contractors as well. At the low end, 53%s of HHS R&D contractors are defense R&D contractors.

expenditures). R&D contractors receive more grant funding ($0.9 million vs. $0.1 million per year). These differences persist when comparing R&D contractors with other firms within the same industry, as shown in Appendix Table H26.

Table 2: R&D Contractors vs. Other Firms

	(1)	(2)	(3)	(4)	(5)	(6)
	Difference in means		R&D contractors		Other firms	
	R&D contractors - Other firms	t	Mean	Std. dev.	Mean	Std. dev.
Sales ($ mm)	4,987.23	45.75	5,983.2	21,058.2	996.0	4,585.8
R&D expenditures ($ mm)	230.53	46.30	264.4	929.5	33.9	128.2
R&D intensity	-4.49	-3.42	1.4	29.4	5.9	174.6
Publications per $1 mm in R&D exp.	0.17	4.02	0.4	5.4	0.3	4.2
Patents per $1 mm in R&D exp.	-0.66	-1.64	0.6	3.5	1.2	53.6
All grants ($ mm)	0.76	6.38	0.9	10.7	0.1	8.7

Notes: This table displays mean comparison tests between R&D contractors and other firms. *R&D intensity* is calculated as R&D expenditures divided by sales. *All grants* are only summarized for fiscal years 2001-2015. The two-sample t-tests use unequal variances.

4 Econometric Specifications

Our econometric analysis proceeds in three steps. First, we estimate the relationship of R&D contracts with R&D expenditures, publications, and patents. We focus on R&D contracts because winning a competitive R&D contract is typically how firms access guaranteed demand (i.e., noncompetitive product contracts) for technology-intensive products.[22] Moreover, the size of the R&D contract proxies for the size of the subsequent public demand.

Second, we explore the potential mechanism behind the effect. We examine the relationship between R&D contracts and future downstream contracts to test to what extent the prospect of winning noncompetitive product contracts incentivizes firms to invest in scientific research. We also examine whether the effect of R&D contracts is stronger for larger firms. We expect a stronger effect for larger firms because they have the significant manufacturing capabilities and complementary assets required to perform on downstream product contracts. We also examine whether R&D contracts play the same role as grants. We expect contracts to have an effect beyond simply providing financial resources that lower the cost of

[22]The Joint Light Tactical Vehicle competition illustrates the relationship between R&D contracts and subsequent product contracts. AM General, Lockheed Martin, and Oshkosh each won R&D contracts in 2012 for the engineering and manufacturing development phase, totaling approximately $185 million. This positioned Oshkosh to win a $6.7 billion contract in 2015 for low-rate initial production of 16,901 vehicles. Full-rate production for an additional 54,600 vehicles will continue through 2042 (Congressional Research Service, 2020).

performing R&D. Then, we examine how the effect of R&D contracts on publications varies with private market incentives to invest in science. We expect guaranteed demand to drive upstream R&D when private market incentives to conduct risky research are weak. We test three such conditions, when the research is (i) not used in the internal inventions of the firm, (ii) used by close product-market competitors, and (iii) not protected by patents.

Third, we explore temporal changes in the composition of procurement contracts (to support Figure 1) and in the relationship between procurement contracts and firm scientific capabilities (to support Figure 2).

4.1 R&D, Publication, and Patent Equations

We estimate the following specification for the relationship between procurement contracts and corporate R&D expenditures, publications, and patents (denoted by $y_{i,t}$):

$$\ln(y_{i,t}) = \alpha_0 + \alpha_1 \ln(R\&D\ contracts_{i,t-3}) + \boldsymbol{Z}'_{i,t-3}\boldsymbol{\omega} + \boldsymbol{\eta}_i + \boldsymbol{\tau}_t + \epsilon_{i,t} \tag{1}$$

$R\&D\ contracts_{i,t-3}$ are R&D contracts awarded to focal firm i in year $t-3$.[23] The vector $\boldsymbol{Z}$ includes time-varying controls, such as the natural logarithms of sales, R&D stock, and government grants. The vectors $\boldsymbol{\eta}$ and $\boldsymbol{\tau}$ are firm and year fixed effects, respectively, and ϵ is an *iid* error term. All dollar values are adjusted using the GDP Implicit Price Deflator to reflect constant 2012 dollars (U.S. Bureau of Economic Analysis, 2021). When calculating natural logarithms, we add \$1 to contract, grant, and instrumental variables, and one unit to publication and patent variables. Standard errors are clustered at the firm level.

Corporate R&D activities can be "company-funded" (using the firm's own funds) or "customer-funded" (under contractual arrangements with federal agencies and other customers). We leverage the fact that company-funded R&D costs are included in *R&D expenditures*, while customer-funded R&D costs are expensed under *Cost of sales* as incurred.[24] Therefore, if $\hat{\alpha_1} > 0$ in the R&D expenditures equation, then government R&D contracts "crowd in" company-funded R&D.

We expect $\hat{\alpha_1} > 0$ in the publication equation. Public demand can mitigate such private market inefficiencies as missing demand for upstream R&D or appropriability concerns due to incomplete exclusivity from weak patent rights (especially for scientific knowledge outside life sciences and chemicals). Guaranteed public demand is a substitute for a less efficient

[23] In Appendix G we show that our results are not sensitive to specific lag structures.

[24] Independent R&D costs can be recovered as general and administrative overhead costs (i.e., indirect costs) on federal procurement contracts, as long as they are allowable, allocable, and reasonable, in accordance with Federal Acquisition Regulation Part 31. However, the firm still bears the risk of performing the R&D in hopes of recovering it from future sales.

patent mechanism for securing private returns to risky upstream R&D.

Conversely, there are several reasons why we expect no or little effect of procurement contracts on patents. First, guaranteed demand may reduce the need to exclude rivals via costly patenting. Second, some government contracts may prohibit patenting altogether (e.g., those for sensitive defense technologies), though other research suggests that this is not a significant concern for most contractors (Howell et al., 2021). Third, private market incentives may already be stronger for downstream R&D, rendering guaranteed public demand less effective in driving corporate technology development.

4.2 Identification Strategy

A major econometric challenge is how to deal with the endogeneity of contracts. Common shocks can affect both corporate R&D activity and contract funding. If the government targets firms that experience positive technological or demand shocks, $\hat{\alpha_1}$ are upward-biased. However, if contracts target firms that experience negative shocks, $\hat{\alpha_1}$ are downward-biased.

We implement two strategies to mitigate this concern. First, we construct several instrumental variables that exploit variation in industry- and agency-level funding to predict firm-level R&D contracts. Our first instrument uses industry-level R&D contracts to predict firm-level R&D contracts, building on Moretti et al. (2021). This instrument allows us to predict R&D contracts for sample firms over time and to estimate the effect of R&D contracts controlling for time-invariant firm heterogeneity.

Changes in industry-level R&D contracts may be related to unobserved or mismeasured technology or demand shocks that directly affect firm-level R&D decisions. To address this possibility, our second instrument exploits variation in the difference between the *estimated* budget authority proposed by the Executive Branch and the *actual* budget authority appropriated by Congress for each federal agency, building on Dugoua, Gerarden, Myers, and Pless (2022).[25] Demand for funding is a function of the common technological shock that can affect both public procurement and corporate R&D activity. However, the actual budget appropriated by Congress includes a component that is independent of this shock (Dugoua et al., 2022). We use the agency-level windfalls that result from the political negotiation between the Executive Branch and Congress to predict firm-level R&D contracts.

The proposed budget may take into account the bargaining power affecting the appropriated budget. To address this possibility, our third instrument exploits variation in Department of Defense windfall funding. Due to its strong bargaining position, DoD's proposed budget is more likely to be appropriated by Congress (e.g., in times of national defense

[25] We use information on each of 12 main federal agencies (plus an "Other" category for smaller agencies).

emergencies) and thus affect the appropriations of other agencies. We use the DoD budget windfall as a source of exogenous variation in other agencies' budget windfalls. Then, we use the DoD-predicted agency-level windfalls to predict firm-level R&D contracts.

Second, we exploit a quasi-natural experiment around the collapse of the former Soviet Union. The end of the Cold War triggered a massive reallocation of government procurement contracts. Changes in funding were driven by geopolitical forces arguably unrelated to technological shocks.[26] Our fourth instrument exploits changes between the pre- and post-Soviet collapse periods in industry-level contracts to predict firm-level R&D contracts. Because this instrument does not vary within firms (i.e., there is only one change per firm), we cannot use the traditional firm fixed-effects methodology. Instead, we follow Blundell, Griffith, and Van Reenen (1999) and include the pre-sample mean of the dependent variable as a separate control for time-invariant firm heterogeneity.

The aforementioned industry- and agency-level shocks, as well as the Cold War shock, could have affected public demand and private demand in similar ways. To address this possibility, we also exploit the end of the Cold War in a panel event study. We focus on industries that benefited from the redeployment of federal funding during 1990-1994, but were otherwise not affected by the end of the Cold War.

We describe the two identification strategies in detail below.

4.2.1 Aggregate Funding as Instruments for Firm R&D Contracts

One identification strategy might be to instrument for a focal firm's R&D contracts using R&D contracts awarded by all federal agencies to its four-digit industry (SIC4). However, this instrument may still be endogenous (e.g., when a firm dominates its SIC4 industry, it is possible that industry R&D contracts and firm R&D activity respond to the same technological shocks). Hence, we take advantage of changes in R&D funding at a higher level of aggregation, the three-digit industry (SIC3). We "distribute" these changes across SIC4 industries according to time-invariant industry shares. Doing so lowers the power of our instrument in the first stage, but increases its validity.

We follow Moretti et al. (2021) and build our first instrument as $Industry\ R\&D\ funding_{i,t} = (Industry\ R\&D\ contracts_{SIC3,t} - Firm\ R\&D\ contracts_{i,t}) \times Industry$

[26]The end of the Cold War may have been precipitated by strategic DoD investments (e.g., the Strategic Defense Initiative, or "Star Wars program," introduced by President Reagan in 1983 to neutralize the Soviet nuclear arsenal). To test for this possibility, we exclude DoD contracts and examine the effect of R&D contracts from civilian federal agencies, whose procurement funding should not have accelerated the collapse of the Soviet Union. We also test the effect of R&D contracts on publications using two alternative shocks. The Global War on Terrorism and the Financial Crisis both triggered massive redeployment of federal procurement funds. Yet, these shocks are unlikely to suffer from the same endogeneity problem as the Cold War shock.

$share_{SIC4,SIC3}$. *Industry R&D contracts*$_{SIC3,t}$ is the total value of all R&D contracts awarded by federal agencies to the focal firm's SIC3 industry in year t. *Firm R&D contracts*$_{i,t}$ is the value R&D contracts awarded to the focal firm in year t. *Industry share*$_{SIC4,SIC3}$ is calculated by dividing the total value of R&D contracts awarded to the focal firm's SIC4 industry during 1980-2015 by the total value of R&D contracts awarded to the focal firm's higher-level SIC3 industry during 1980-2015.[27] Additional details on this instrument and an example are included in Appendix D.

We build our *Agency windfall funding*$_{i,t}$ instrument by replacing *Industry R&D contracts*$_{SIC3,t}$ in the first instrument with $\sum_{Agencies}$ *Windfall funding*$_{Agency,t}$ $\times$ *Agency share*$_{SIC3,t,Agency}$. Here, *Windfall funding*$_{Agency,t}$ is the value of windfall budget authority appropriated to the focal agency in year t.[28] *Agency share*$_{SIC3,t,Agency}$ is calculated by dividing the total value of R&D contracts awarded by the focal agency to the focal firm's SIC3 industry in year t by the total value of R&D contracts awarded by the focal agency in year t.

We build our *DoD-predicted windfall funding*$_{i,t}$ instrument by replacing *Windfall funding*$_{Agency,t}$ in the second instrument with *DoD-predicted windfall funding*$_{Agency,t}$. Here, *DoD-predicted windfall funding*$_{Agency,t}$ is the predicted value of the focal agency's windfall budget authority in year t, obtained after regressing the focal agency's windfall budget authority on the DoD windfall budget authority.[29]

4.2.2 Quasi-Natural Experiment: The End of the Cold War

During the Cold War (1948-1989), government procurement focused on achieving and sustaining technological superiority for the purpose of national security (Weiss, 2014). The large scale and long duration of Cold War threats led to procurement budgets that were dominated by the Department of Defense and exceeded previous peacetime expenditures (Mowery, 2012). The end of the Cold War removed the perception of an existential threat to the United States and drove a significant reallocation of procurement priorities. Between 1988 and 1992, DoD procurement obligations dropped 38%, while HHS obligations almost tripled (from a much smaller baseline).[30]

[27] Total values include all R&D contracts awarded by all federal agencies to all recipients, not just those contracts matched to sample firms.

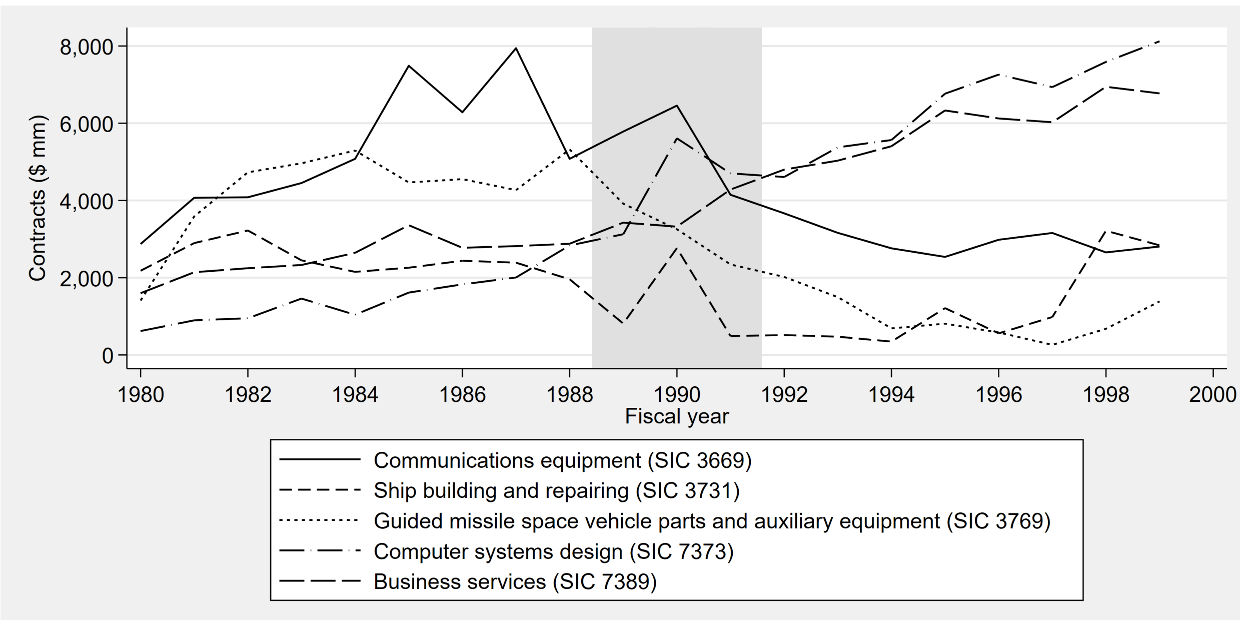
[28] Each annual *Budget of the U.S. Government* gives us two pieces of information on federal agency funding: the estimated amount requested by the agency and the actual amount appropriated by Congress. The difference between actual and estimated amounts represents the windfall budget authority.

[29] We run separate OLS regressions for each agency, and include (i) a control for the DoD requested budget authority and (ii) an indicator variable identifying years when the *budget authority by agency* table in the *Budget of the U.S. Government* includes only discretionary funding.

[30] DoD awarded \$225.9 billion in contracts in 1988 and \$140.1 billion in 1992 (using constant 2012 dollars). HHS awarded \$830 million in 1988 and \$2.3 billion in 1992.

Overall, government demand declined between 1988 and 1992.[31] On average, industries experienced a $84 million reduction in federal procurement contracts. Yet, not all industries were equally affected, as can be seen in Figure 4 and Appendix Table H27. Among the "winners" receiving increased procurement funding after the end of the Cold War were IT industries (e.g., computer systems design) and health industries (e.g., medicinal chemicals and botanical products). Among the "losers" were the national security industries (e.g., guided missiles and space vehicles). Because the reallocation between industries was caused by geopolitical circumstances unrelated to technological shocks, we exploit the end of the Cold War as a quasi-natural experiment.

Figure 4: Procurement During and After the Cold War



Notes: This figure plots the aggregate value of procurement contracts awarded by federal agencies to various industries. Dollar values are adjusted using the GDP Implicit Price Deflator to reflect constant 2012 dollars (U.S. Bureau of Economic Analysis, 2021).

Appendix Figure D1 shows the timeline used to calculate our fourth instrumental variable. Specifically, we take advantage of variation in the value of all contracts awarded to various industries to instrument for R&D contracts awarded to firms during 1995-2015.[32] Many of our sample firms operate in multiple business segments, so they were affected by changes in procurement contracts across multiple industries. To estimate the "average" shock experienced

[31] Federal agencies collectively awarded $299 billion in procurement contracts in 1988 and $234 billion in 1992 (using constant 2012 dollars).

[32] We begin the analysis period in 1995 to account for the three-year lag between the R&D contract award and publishing or patenting the resulting findings.

by each firm, we use the shares of firm sales in each industry as weights. We calculate this second instrumental variable as $Cold\ War\ shock_i = \sum_j \Delta Contracts_j \times Share\ of\ sales_{i,j}$. Here, $Cold\ War\ shock_i$ is the instrument for firm i, and it does not vary over time. The subscript j indexes SIC4 industries. We calculate $\Delta Contracts_j$ as the difference between the average contracts awarded to industry j in the pre- (1986-1988) and post- (1990-1992) periods. $Share\ of\ sales_{i,j}$ is the share of firm i's sales during 1982-1985 in industry j, calculated using the Compustat Segments dataset (Standard & Poor's, 2018).[33] We use a multi-year lag in calculating the share of sales to alleviate concerns that firms might have anticipated the end of the Cold War. Under that scenario, firms might have entered industries where they anticipated growing procurement funding and exited industries where they anticipated shrinking procurement funding.

In our panel event study, we examine firms in SIC2 industries that experienced a positive procurement shock (i.e., a large increase in all contracts) in the years immediately following the end of the Cold War.[34] A "large" increase represents a year-over-year change in procurement contracts awarded to the industry that is in the top quintile of the distribution of changes between 1989 and 1994. Moreover, we require that the positive procurement shock not be accompanied by a total demand shock (i.e., the year-over-year change in sales to the industry was in the bottom four quintiles of the distribution of changes in sales between 1989 and 1994).[35] Doing so allows us to isolate the effect of increasing public demand when there was no corresponding increase in total demand.

With this event, we estimate the following specification:

$$ln(Y)_{it} = \sum_{j=2}^{5} \gamma_j \, (Lead\ j)_{it} + \sum_{k=0}^{5} \delta_k \, (Lag\ k)_{it} + \boldsymbol{Z}'_{i,t}\boldsymbol{\omega} + \boldsymbol{\eta_i} + \boldsymbol{\tau_t} + \epsilon_{i,t} \qquad (2)$$

Y_{it} is *R&D expenditures*, *Private demand* (calculated as sales net of procurement contracts), *Publications*, and *Patents*, respectively, for firm i in year t. Leads and lags are indicator vari-

[33] For example, Komatsu Ltd. operated only in industry 3531 Construction Machinery and Equipment during 1982-1985, generating 100% of its sales in that industry. As a result, its *Cold War shock* came entirely from reallocations in contracts awarded to industry 3531. Caterpillar Inc. generated 76% of its sales during 1982-1985 in industry 3531 Construction Machinery and Equipment, and 24% in industry 3519 Internal Combustion Engines, Not Elsewhere Classified. As a result, 76% of this firm's *Cold War shock* came from reallocations in contracts awarded to industry 3531, and 24% from reallocations to industry 2519.

[34] Using high-level, 2-digit definitions of industries allows us to reduce industry-level concentration; 95% of sample firms had sales during 1985-2015 that represented less than 5.2% of total SIC2 industry sales.

[35] The median year-over-year change in procurement contracts awarded to a SIC2 industry during 1989-1994 was a 10% decrease. Top quintile industries had an increase greater than 38.2%. Over the same period, the median year-over-year change in sales to a SIC2 industry was a 3.4% increase. Top quintile industries had an increase greater than 14.6%. We used these thresholds ($\geq$ 38.2% increase in procurement, $<$ 14.6% increase in sales) to identify SIC2 industries for the event study.

ables defined as: $(Lead\ j)_{it} = \mathbb{1}[t\ = Event_{shock} - j]$ and $(Lag\ k)_{it} = \mathbb{1}[t = Event_{shock} + k]$. $Event_{shock} \in \{1990,\ ...,\ 1994\}$ is the year of the shock. The vector $\boldsymbol{Z}$ includes such controls for the natural logarithm of private demand and the percentage change in private demand. The vectors $\boldsymbol{\eta}$ and $\boldsymbol{\tau}$ are firm and year fixed effects, respectively, and ϵ is an *iid* error term.

The sample for the event study includes 1,904 firms in 21 industries. Treatment is the positive procurement shock, and it is staggered (i.e., different SIC2 industries are shocked at different times in the 1989-1994 time frame). The 340 firms (spanning 18 industries) that received procurement contracts during 1980-1984 represent the treated group, while the remaining 1,564 firms (spanning 21 industries) represent the control group. Treated firms remain treated for the complete duration of the sample. We assume there is no anticipation.[36]

4.3 Trends in the Composition of Contracts

We estimate the following specification for trends in the value and composition of government procurement contracts:

$$\ln(Contracts_{i,t}) = \beta_0 + \beta_1 Time\ trend_t + \boldsymbol{Z}'_{i,t-1}\boldsymbol{\omega} + \boldsymbol{\eta}_i + \epsilon_{i,t} \tag{3}$$

We report specifications where we use the different types of procurement contracts described in Section 3, including R&D contracts and commercial contracts, as the dependent variable. We also report results where the dependent variable is the share of R&D or commercial contracts in all contracts. The indices i and t denote firms and years, respectively. $Time\ trend_t$ is the focal year t minus 1980, presented in decennial units. The other elements of the specification are the same as described in Section 4.1.

We are interested in the estimate of β_1. Consistent with the trends in Figure 1, we expect $\hat{\beta}_1 < 0$ for the share of R&D contracts regression and $\hat{\beta}_1 > 0$ for the share of commercial contracts regression.[37]

[36] As reported in Section 5.4, treated and control firms follow parallel trends prior to the shock.

[37] The Federal Acquisition Streamlining Act of 1994 aimed to attract nontraditional suppliers to the government market. Therefore, it is possible that entry from firms with limited R&D capabilities changed the composition of the pool of federal contractors over time.

4.4 Trends in the Relationship Between Contracts and Firm Scientific Capabilities

We estimate the following specification for changes in the relationship between contract value and firm scientific capabilities over time:

$$\begin{aligned} \ln(Contracts_{i,t}) &= \gamma_0 + \gamma_1 Time\ trend_t + \gamma_2 \ln(Publications\ stock_{i,t-1}) \\ &+\gamma_3 Time\ trend \times \ln(Publications\ stock_{i,t-1}) + \boldsymbol{Z}'_{i,t-1}\boldsymbol{\omega} + \boldsymbol{\eta}_i + \epsilon_{i,t} \end{aligned} \quad (4)$$

$Contracts_{i,t}$ is the flow of procurement contracts awarded to firm i in year t. $Time\ trend_t$ is the focal year t minus 1980, presented in decennial units. $Publications\ stock_{i,t-1}$ is calculated using a perpetual inventory method with a 15% depreciation rate (similar to Hall, Jaffe, & Trajtenberg, 2005). The other elements of the specification are described in Section 4.1.

We are interested in the estimate of γ_3 and expect $\hat{\gamma}_3 < 0$. This prediction is consistent with the view that the importance of scientific capabilities for getting government contracts has decreased over time (as contracts have increasingly been awarded for commercial items and dual-use technologies).

5 Estimation Results

5.1 R&D Expenditures Equation

Table 3 presents the within-firm estimation results for the R&D equation. Column 1 presents OLS results. *R&D expenditures* have a positive relationship with *R&D contracts* (p-value $<$ 0.001).[38] Our coefficient estimate is smaller than the 0.047 estimate obtained by Lichtenberg (1988) when using only defense R&D and defense contractors, but larger than the 0.006 estimate obtained by Moretti et al. (2021) when using only defense R&D and French firms.[39]

Columns 2-5 present causal estimates using two-stage least squares (2SLS). In the first stage for Column 2, we predict *R&D contracts* awarded to a focal firm using the *Industry R&D funding* instrument (see Column 1 in Appendix Table D6). The first stage results confirm that firm-level R&D contracts are a function of industry-level R&D funding. In the second stage, we estimate *R&D expenditures* as a function of the predicted R&D contracts

[38] Results are not sensitive to how we control for firm size. In unreported specifications, we obtain coefficient estimates on *R&D contracts* of 0.007 when we use *Sales* as a size control and 0.011 when we drop the size control altogether.

[39] In an unreported specification, we eliminate the control for *R&D stock*, reduce the lag to one year, and cluster standard errors at the SIC3 level to more closely match the specification used in Table 4, Column 1 of Moretti et al. (2021). We obtain a coefficient estimate of 0.012, compared to their coefficient estimate of 0.011.

Table 3: Estimation Results for the R&D Expenditures Equation

	(1)	(2)	(3)	(4)	(5)
	ln(R&D expenditures)				
	OLS: Within firms	IV: Industry R&D funding	IV: Agency windfall funding	IV: DoD-predicted windfall funding	IV: Cold War shock
ln(R&D contracts)$_{t-3}$	0.008	0.070	0.080	0.079	0.139
	(0.002)	(0.026)	(0.028)	(0.028)	(0.059)
ln(R&D stock)$_{t-3}$	0.346	0.327	0.330	0.328	1.150
	(0.017)	(0.018)	(0.018)	(0.018)	(0.018)
Pre-sample mean R&D expenditures					-0.268
					(0.038)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1995-2015
Firm fixed effects	Yes	Yes	Yes	Yes	No
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		96.02	95.56	94.43	14.84
Firms	3,465	3,414	3,386	3,391	
Observations	39,841	37,052	35,855	35,991	4,965
Adjusted R-squared	0.914	0.048	0.039	0.039	0.813

Notes: This table presents the estimation results for the relationship between R&D contracts and R&D expenditures. In Columns 2-5, R&D contracts are instrumented using *Industry R&D funding*, *Agency windfall funding*, *DoD-predicted windfall funding*, and the *Cold War shock*, respectively. In Column 5, the pre-sample mean of R&D expenditures uses data from 1980-1988. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level in Columns 1-4, and are heteroskedasticity-robust in Column 5.

(see Column 2 in Table 3). As expected, $\hat{\alpha}_1 > 0$. The 2SLS estimate is statistically significant (p-value < 0.01) and larger than OLS, suggesting that contracts might target fields affected by negative technological or demand shocks. Evaluated at the sample means, the estimate indicates that a \$1 million increase in R&D contracts leads to a \$0.57 million increase in R&D expenditures.[40] In Appendix Table G11, we exclude contracts from the seven largest agencies one by one and find that our results are not driven by any single awarding agency.

In Columns 3 and 4, we instrument *R&D contracts* using *Agency windfall funding* and *DoD-predicted windfall funding*, respectively. The coefficient estimates are significant (p-value < 0.01) and sightly larger in magnitude, suggesting that windfall funding resulting from the political negotiation process in Congressional appropriations further resolves the downward bias observed in OLS.

[40] Average values for R&D expenditures and R&D contracts are \$107.4 million and \$13.2 million, respectively. The marginal effect of an additional \$1 million in R&D contracts is $0.070(107.4)/(13.2 + 0.000001) = 0.57$ million in R&D expenditures.

In Column 5, we exploit the *Cold War shock* as a quasi-natural experiment for exogenous changes in government funding across industries. In the first stage, we predict *R&D contracts* awarded to a focal firm using our instrument (see Column 2 in Appendix Table D6) and find that firm-level R&D contracts are a function of changes in industry funding triggered by the end of the Cold War. In the second stage, we estimate *R&D expenditures* as a function of the predicted R&D contracts (see Column 5 in Table 3). Because the instrument does not vary over time, we report pooled estimates and rely on pre-sample information regarding R&D expenditures to replace the unobservable firm fixed effect (similar to Blundell et al., 1999). The coefficient estimate indicates a positive causal effect of R&D contracts on R&D expenditures (p-value < 0.05).

In summary, the causal estimates suggest that R&D contracts "crowd in" corporate R&D investments, which is consistent with the prior literature (e.g., Moretti et al., 2021).

5.2 Publication Equation

Table 4 presents the estimation results for publications, our measure of upstream corporate R&D. In Column 1, *Publications* are positively related to *R&D contracts* (p-value < 0.001).[41]

Columns 2-4 show results from the second stage of 2SLS regressions using *Industry R&D funding*, *Agency windfall funding*, and *DoD-predicted windfall funding* as the instrumental variable, respectively. Evaluated at the sample means, the coefficient estimate in Column 3 suggests that \$14.7 million in additional R&D contracts leads to one additional publication.[42] The 2SLS estimates are larger than the OLS estimate, suggesting that government contracts target firms where corporations face negative technology or demand shocks.

Column 5 presents the estimation results using the *Cold War shock*. Evaluated at the sample means, the estimate indicates that to obtain one additional publication, R&D contracts need to increase by just \$0.112 million.[43] This estimate is substantially larger than the estimates from Columns 2-4, for three potential reasons. The set of firms differs across approaches.[44] Our first three instruments may not fully resolve the downward bias in OLS

[41] In unreported specifications, we obtain similar coefficient estimates on *R&D contracts* when we replace *R&D stock* with *Sales* or drop the size control altogether. When we split R&D contracts into "R" vs. "D" contracts, we find coefficient estimates that are positive, statistically different from zero, and similar in magnitude. This suggests that publications have similar relationships with research contracts and development contracts, respectively.

[42] Average values for publications and R&D contracts are 13 and \$9 million, respectively. The marginal effect of an additional \$1 million in R&D contracts is $0.044(13+1)/(9+0.000001) = 0.068$ publications.

[43] Average values for publications and R&D contracts are 36 and \$1.4 million, respectively. The marginal effect of an additional \$1 million in R&D contracts is $0.336(36+1)/(1.4+0.000001) = 8.9$.

[44] The analysis sample in Column 5 is restricted to firms for which we can calculate pre-sample mean publications during any portion of 1980-1988 and exposure to sales in various industries during any portion of 1982-1985. The actual regressions use data for 1995-2015. The range in coefficient estimates likely reflects

Table 4: Estimation Results for the Publication Equation

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(Publications)					ln(Citation-weighted publications)
	OLS: Within firms	IV: Industry R&D funding	IV: Agency windfall funding	IV: DoD-predicted windfall funding	IV: Cold War shock	IV: Agency windfall funding
ln(R&D contracts)$_{t-3}$	0.011	0.034	0.044	0.034	0.336	0.049
	(0.002)	(0.018)	(0.019)	(0.019)	(0.095)	(0.022)
ln(R&D stock)$_{t-3}$	0.131	0.114	0.115	0.116	0.119	0.106
	(0.011)	(0.010)	(0.011)	(0.011)	(0.017)	(0.011)
Pre-sample mean publications					0.448	
					(0.088)	
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1995-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		99.94	101.29	98.34	15.68	101.29
Firms	3,632	3,580	3,558	3,561		3,558
Observations	43,914	41,047	39,767	39,913	5,861	39,767
Adjusted R-squared	0.873	0.016	0.007	0.016	-0.044	-0.003

Notes: This table presents the estimation results for the relationship between R&D contracts and publications. In Columns 2-6, R&D contracts are instrumented using *Industry R&D funding*, *Agency windfall funding*, *DoD-predicted windfall funding*, *Cold War shock*, and *Agency windfall funding*, respectively. In Column 5, the pre-sample mean of publications uses data from 1980-1988. In Column 6, the publication flow is weighted by citations received from other publications, normalized by journal-year. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level in Columns 1-4 and 6, and are heteroskedasticity-robust in Column 5.

because they rely on time-invariant exposure shares that could still be correlated with firm-specific, time-invariant heterogeneity. And, the Cold War instrument may not fully remove time-invariant firm heterogeneity using the pre-sample mean, making it even more sensitive to the temporal reallocation of contracts away from innovating firms (as shown in Figure 2 and Section 5.6).

Our analysis thus far has focused on the number of corporate publications, rather than on their quality. In Column 6, we control for quality using citations. Specifically, we weigh each publication by the number of citations received from other publications.[45] This gives us a quality-adjusted measure of corporate upstream R&D. The coefficient estimate suggests that firms are not simply increasing the number of publications while lowering their quality

the changing composition of our sample over a very long panel, with Cold War-era firms being more likely than newer firms to rely on (or respond to) public demand. Section 5.6 examines how the effect of contracts on publications has changed over time.

[45] We use normalized citations, calculated as (Forward citations received from other publications up to the year 2016) / (Average forward citations received by all publications published in the same journal and year).

in response to winning R&D contracts (p-value < 0.05).

In summary, we find evidence supporting the view that public demand drives upstream R&D, as measured by corporate publications. Appendix Sections F and G suggest that the effect of R&D contracts on publications is present across all industries, and is robust to excluding contracts from each of the main agencies or using other funding shocks, alternative specifications, different time lags, and firm subsamples. Moreover, we find no evidence to suggest that R&D contracts crowd out unrelated research areas.

5.3 Patent Equation

Table 5 presents the within-firm estimation results for patents, our measure of downstream corporate R&D. In Column 1, *Patents* have a positive relationship with *R&D contracts* (p-value < 0.001).[46]

Estimation results using *Industry R&D funding*, *Agency windfall funding*, *DoD-predicted windfall funding*, and the *Cold War shock* as instrumental variables are included in Columns 2-5, respectively. The coefficient estimates on R&D contracts are no longer statistically different from zero. Interpreted together, these results cast doubt on the existence of a causal relationship between R&D contracts and patents. There are two potential explanations for this result. First, guaranteed public demand may reduce the need to exclude rivals through patenting. Second, market incentives are likely to be stronger for downstream development, rendering guaranteed public markets less important.

In Column 6, we use a quality-adjusted measure of downstream R&D. Specifically, we weigh the flow of corporate patents by the number of citations received by each focal patent from other patents.[47] The coefficient estimate suggests that firms are not simply becoming more selective in their patent applications in response to winning R&D contracts.

In summary, we do not find evidence that public demand drives firms to invest in downstream R&D, as measured by patents. Given our publication equation results, this highlights the importance of distinguishing between scientific research ("R") and downstream development ("D") in corporate R&D.

[46] In unreported specifications, we obtain similar coefficient estimates on *R&D contracts* when we replace *R&D stock* with *Sales* or drop the size control altogether.

[47] We use normalized citations, calculated as (Forward citations it received from other patents up to the year 2016) / (Average forward citations received by all granted patents in the same 4-digit International Patent Classification (IPC) and year).

Table 5: Estimation Results for the Patent Equation

	(1)	(2)	(3)	(4)	(5)	(6) ln(Citation-weighted Patents)
	ln(Patents)					
	OLS: Within	IV: Industry R&D funding	IV: Agency windfall funding	IV: DoD-predicted windfall funding	IV: Cold War shock	IV: Agency windfall funding
ln(R&D contracts)$_{t-3}$	0.010	-0.040	-0.030	-0.042	0.059	-0.044
	(0.002)	(0.023)	(0.025)	(0.025)	(0.050)	(0.027)
ln(R&D stock)$_{t-3}$	0.252	0.241	0.242	0.243	0.358	0.224
	(0.015)	(0.015)	(0.015)	(0.015)	(0.014)	(0.015)
Pre-sample mean patents					0.416	
					(0.046)	
negative$_hwindfall_lag3$				0.000		
				(.)		
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1995-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		99.94	101.29	98.34	24.44	101.29
Firms	3,632	3,580	3,558	3,561		3,558
Observations	43,914	41,047	39,767	39,913	5,861	39,767
Adjusted R-squared	0.847	0.045	0.056	0.046	0.631	0.025

Notes: This table presents the estimation results for the relationship between R&D contracts and patents. In Columns 2-6, R&D contracts are instrumented using *Industry R&D funding*, *Agency windfall funding*, *DoD-predicted windfall funding*, *Cold War shock*, and *Agency windfall funding*, respectively. In Column 5, the pre-sample mean of patents uses data from 1980-1988. In Column 6, the patent flow is weighted by citations received from other patents, normalized by International Patent Classification (IPC) class-year. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level in Columns 1-4 and 6, and are heteroskedasticity-robust in Column 5.

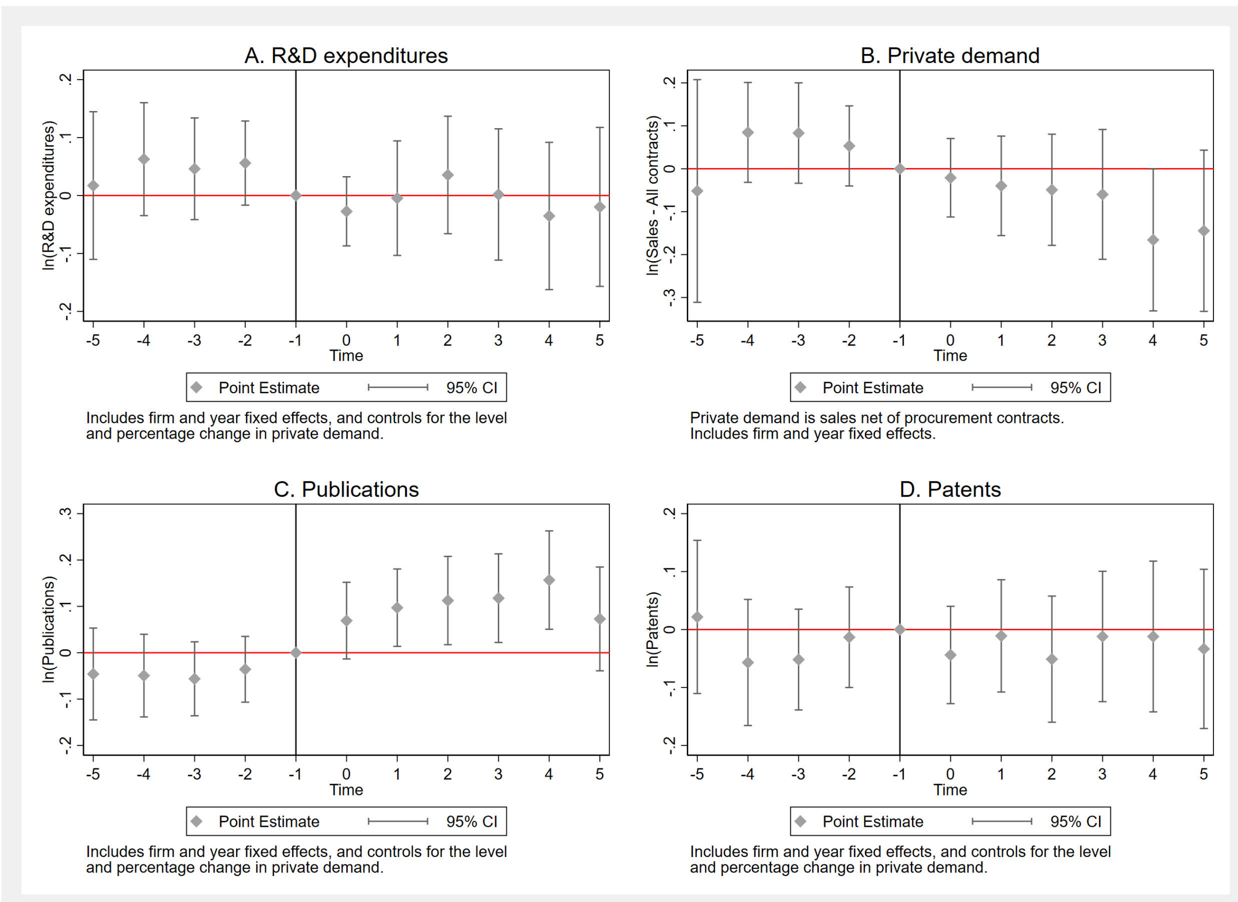
5.4 Event Study Analysis: The End of the Cold War

Figure 5 presents results from the Cold War event study. The point estimates capture the difference between treated and control groups compared to the prevailing difference in the omitted base period (i.e., year -1, indicated with a vertical line). Each vertical bar shows a 95% confidence interval. The coefficient estimates on pre-treatment years (i.e., years -5, -4, -3, -2, and -1) indicate that we have parallel pre-trends in all specifications. This suggests that firms don't anticipate the procurement shocks. All models use firm fixed effects to absorb firm-specific, time-invariant heterogeneity, as well as year fixed effects to absorb time trends in our staggered treatment design. Estimations use firms that have data for the entire 11-year period to control for changes in the composition of industries over time.

Panel A suggests that treated firms don't change their R&D expenditures after the procurement shock, which is different from our regression results in Table 3. Panel B shows that private demand does not increase for treated firms relative to control firms after the procurement shock, confirming that we have successfully controlled for changes in private demand in constructing our event study sample. Panel C indicates that treated firms increase their publishing after the procurement shock, consistent with the estimation results in Table 4. Meanwhile, Panel D shows no statistically significant decrease in patenting after the procurement shock, consistent with the results in Table 5.

In summary, the event study confirms the regression results regarding the average effect of procurement contracts on corporate publications and patents.

Figure 5: Event Study Around the End of the Cold War



Notes: This figure presents an event study around the end of the Cold War. The point estimates capture the difference between treated and control firms compared to the prevailing difference in the omitted base period (i.e., year -1, indicated with a vertical line). The specifications in Panels A, C, and D use controls for the level and percentage change in private demand (i.e., sales net of procurement contracts). All specifications use firm fixed effects and year fixed effects, and are estimated using firms that have data for the entire 11-year period. One is added to logged variables. Standard errors are clustered at the firm level.

5.5 R&D Contracts as a "Ticket" to Downstream Contracts

We explore whether the prospect of winning large downstream product contracts incentivizes firm investments in research.[48] In Table 6, we estimate the relationship between winning R&D contracts and future downstream contracts. Consistent with the premise that R&D contracts are the "ticket to play" in the government market, the coefficient estimates in Column 3 show that winning R&D contracts is positively associated with the value of future procurement contracts (p-value < 0.001), while winning grants is not. Columns 4 and 5 indicate that our results are robust to using different measures of future downstream procurement contracts.

Table 6: THE RELATIONSHIP BETWEEN R&D CONTRACTS AND DOWNSTREAM CONTRACTS

	(1)	(2)	(3)	(4)	(5)
	ln(All contracts)			ln(Noncompetitive contracts)	Share noncompetitive/ non-R&D contracts
	Contract indicator	Grant indicator	Contract and grant indicators	Contract and grant indicators	Contract and grant indicators
$[\text{Has R\&D contracts} = 1]_{t-1}$	2.667		2.664	0.956	0.307
	(0.154)		(0.154)	(0.145)	(0.085)
$[\text{Has grants} = 1]_{t-1}$		0.266	0.159	-0.335	-0.169
		(0.165)	(0.149)	(0.206)	(0.185)
$\ln(\text{R\&D stock})_{t-1}$	0.414	0.443	0.414	0.373	0.026
	(0.057)	(0.060)	(0.057)	(0.095)	(0.102)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	52,793	52,793	52,793	22,908	21,620
Adjusted R-squared	0.750	0.744	0.750	0.585	-0.027

Notes: This table presents OLS estimation results for the relationship of *R&D contracts* with the value of future downstream procurement contracts. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

5.5.1 Firm Size

Large firms do not need the government to fund their R&D activities, as they can use internal resources or access capital markets.[49] What large firms need is a market to sell the

[48] For example, Mowery (2012) notes that the contract to supply semiconductor components for strategic missile guidance systems was the "prize" that motivated Texas Instruments to develop the integrated circuit.

[49] On average, the contractors in our sample receive \$18 million in R&D contracts per year, an order of magnitude less than the \$232 million they report in cash on hand. Outside our sample, companies in the S&P 500 held a combined \$2.77 trillion in cash as of November 2021. Therefore, liquidity problems do not seem to impede R&D investments for large firms.

products resulting from their R&D, so they can generate returns on investment. Guaranteed public demand should drive upstream R&D in large firms because they are well-positioned to capitalize on the large public market. Table 7 presents the second stage of 2SLS using *Industry R&D funding* to instrument for *R&D contracts*. Column 2 shows that the effect of R&D contracts on publications is strong for firms with above-median sales (p-value < 0.05), underscoring the importance of complementary assets and scale for meeting the complex requirements of downstream procurement.[50]

Table 7: Variation by Firm Size

	(1)	(2)	(3)	(4)
	ln(Publications)		ln(Patents)	
	Small firms	Large firms	Small firms	Large firms
$\ln(\text{R\&D contracts})_{t-3}$	0.004	0.054	-0.053	-0.007
	(0.024)	(0.024)	(0.032)	(0.028)
$\ln(\text{R\&D stock})_{t-3}$	0.017	0.187	0.078	0.384
	(0.008)	(0.019)	(0.011)	(0.028)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)	47.35	63.59	47.35	63.59
Observations	19,603	21,020	19,603	21,020
Adjusted R-squared	-0.001	0.017	-0.019	0.127

Notes: This table presents results from estimating how the effect of R&D contracts on publications and patents varies by firm size. The *Small firms* sample includes firm-years with below-median sales. The *Large firms* sample includes firm-years with above-median sales. Columns 1-4 present the second stage of 2SLS, where *R&D contracts* are instrumented using *Industry R&D funding*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

5.5.2 Controlling for Grants

The guaranteed demand mechanism should be distinct from the financing mechanism. Controlling for grants allows us to show that R&D contracts are not just financial resources that lower the cost of performing R&D. Table 8 confirms that our results are not sensitive to controlling for grants obligated to panel firms by all U.S. federal agencies. R&D contracts still have a positive effect on R&D expenditures (p-value < 0.01 in Column 2) and publications

[50] In unreported specifications, we obtain similar results when we instrument *R&D contracts* using *Agency windfall funding*, *DoD-predicted windfall funding*, and *Cold War shock*, respectively.

(p-value < 0.1 in Column 4), but not on patents.[51] The coefficient estimates are close in size to those reported in Tables 3 and 4, suggesting that contracts and grants capture different mechanisms by which the government influences corporate R&D (guaranteeing demand and lowering cost, respectively).

Our key finding—that R&D contracts drive publications—is consistent with firms investing in scientific research to increase their chances of winning R&D races as a pathway to guaranteed public demand. If contracts drove corporate R&D simply by lowering costs (i.e., the public funding mechanism), we would expect to find an effect on patents as well. Conversely, the effect of guaranteed demand should be stronger when market incentives are weak, which is more likely to occur in the case of upstream R&D than downstream R&D (due to fewer immediate market applications, higher spillovers to rivals, and weaker patent protection).

Table 8: Controlling for Grants

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(R&D expenditures)		ln(Publications)		ln(Patents)	
	OLS: Within firms	IV: Industry R&D funding	OLS: Within firms	IV: Industry R&D funding	OLS: Within firms	IV: Industry R&D funding
ln(R&D contracts)$_{t-3}$	0.008	0.069	0.011	0.033	0.010	-0.043
	(0.002)	(0.026)	(0.002)	(0.018)	(0.002)	(0.023)
ln(All grants)$_{t-3}$	0.009	0.006	0.006	0.004	0.009	0.012
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)
ln(R&D stock)$_{t-3}$	0.347	0.328	0.131	0.114	0.252	0.241
	(0.017)	(0.018)	(0.011)	(0.010)	(0.015)	(0.015)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		93.18		97.22		97.22
Firms	3,465	3,414	3,632	3,580	3,632	3,580
Observations	39,841	37,052	43,914	41,047	43,914	41,047
Adjusted R-squared	0.914	0.050	0.873	0.017	0.847	0.043

Notes: This table presents the estimation results for the relationship of R&D contracts with R&D expenditures, publications, and patents, after controlling for federal grants. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

[51] In unreported specifications, we get even stronger results in the R&D expenditures and publication equations when using the *Cold War shock* as an instrument for *R&D contracts*.

5.5.3 Insufficient Market Incentives

We examine the conditions under which public demand drives firms to invest in upstream R&D, as measured by corporate publications. We provide empirical support for public demand (i.e., procurement contracts) driving corporate scientific research when market incentives are weak by exploiting several sources of variation in our data. We expect R&D contracts to have a larger effect on publications that are (i) not cited by the firm's own patents (missing downstream applications), (ii) cited by rival firms' patents (the science spills over to product-market competitors), and (iii) not protected by the firm's own patents (hence, the science is harder to appropriate).[52]

Table 9 presents the within-firm estimation results from the second stage of 2SLS regressions using *Industry R&D funding* as an instrument for R&D contracts.[53] Columns 1 and 2 compare the effect on publications with and without downstream applications inside the inventing firm. Consistent with our prediction, the coefficient estimate is positive and statistically significant when the science does not have internal use (p-value $<$ 0.05 in Column 2). Evaluated at the sample means, \$24 million in additional R&D contracts leads to one additional publication not cited by the firm's own patents.[54]

Columns 3 and 4 compare the effect of R&D contracts on publications when the science has low vs. high spillover to product-market rivals. Consistent with our prediction, the coefficient estimates indicate that the effect is strong when rival patents cite the firm's publications (p-value $<$ 0.01 in Column 4).[55]

The last two columns compare the effect on publications with low vs. high protection from the firm's own patents. In line with our expectations, the coefficient estimates indicate that the effect is strong when publications are unlikely to be protected by a patent (p-value $=$ 0.06 in Column 6).[56]

In summary, the effect of R&D contracts on corporate science appears to be larger when firms have lower ability to appropriate returns from participating in upstream R&D.

[52] Private market incentives to invest in science depend on the firm's anticipated return on investment in science. Because we do not observe ex-ante measures of private market incentives at the firm-year level, we rely instead on ex-post measures that should be positively correlated with the unobserved ex-ante measures.

[53] The construction of the own use, spillovers, and scope of patent protection measures is detailed in Appendix C.

[54] Average values for publications not used internally and R&D contracts are 13 and \$12 million, respectively.

[55] The samples for Columns 3 and 4 include only firm-years with one or more publications cited by corporate patents.

[56] In unreported specifications, we obtain broadly similar results to Columns 1-6 when R&D contracts are instrumented using *Agency windfall funding* and *DoD-predicted windfall funding*, respectively.

Table 9: Variation by Private Market Incentives to Invest in Science

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(Publications)					
	Internal use	No internal use	Low rival use	High rival use	High protection	Low protection
ln(R&D contracts)$_{t-3}$	0.001	0.035	0.028	0.058	-0.001	0.034
	(0.008)	(0.018)	(0.020)	(0.022)	(0.007)	(0.018)
ln(R&D stock)$_{t-3}$	0.002	0.117	0.056	0.044	0.015	0.114
	(0.004)	(0.011)	(0.013)	(0.015)	(0.004)	(0.010)
ln(Internal use publications)			0.499	0.355		
			(0.036)	(0.049)		
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No	No	Yes	Yes
Weak identif. (Kleibergen-Paap)	99.94	99.94	28.70	28.70	99.94	99.94
Firms	3,580	3,580	638	638	3,580	3,580
Observations	41,047	41,047	4,333	4,333	41,047	41,047
Adjusted R-squared	-0.001	0.016	0.208	0.051	0.001	0.016

Notes: This table presents second stage results from estimating how the effect of R&D contracts on publications varies by private market incentives to invest in science. In Columns 1-6, *Industry R&D funding* is used as an instrument for *R&D contracts*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

5.6 Changes Over Time

We have shown that public markets—through the guaranteed demand mechanism—can drive upstream corporate R&D when private markets provide insufficient incentives to invest in risky scientific research. To the extent that public markets may have become more similar to private markets (e.g., by rewarding technologies that already have commercial success, or by weakening the relationship between R&D races and downstream product contracts), their ability to substitute for private market incentives would have been reduced over time.

To help us understand the implications of procurement policy changes implemented throughout the 1980s and 1990s (as summarized in Appendix A.2), Table 10 presents changes in the composition of procurement contracts, and in the relationship of contracts with firm scientific capabilities over time. Column 1 shows that total contract size increased by 20% per decade (p-value < 0.05), or 82% over the entire sample period.[57]

Columns 2 and 3 show that the increase in procurement value was driven by non-R&D contracts and the rise in commercial contracts (i.e., contracts designed to more closely re-

[57] When dropping the controls for R&D stock, the coefficient estimate on *Time trend* increases to 0.734, indicating that a substantial part of the increase in contract value is explained by sample firms getting bigger over time.

semble the commercial markets, as detailed in Appendix B). The estimates imply that the annual value of R&D contracts decreased by 18% per decade (p-value < 0.05), while the annual value of commercial contracts more than doubled per decade (p-value < 0.001).[58]

In Column 4, the within-firm coefficient estimate shows that the share of R&D contracts in all contracts has remained unchanged. This suggests that the drop in the overall share of R&D contracts in all contracts documented in Figure 1 was driven by entry from nontraditional contractors that perform less corporate R&D. Meanwhile, Column 5 shows that the share of commercial contracts in all contracts increased by 22% per decade between 1995 and 2015 (p-value < 0.001).

Lichtenberg (1984) notes that "federal contracts do not descend upon firms like manna from heaven" (p. 74), but rather respond to firms' own investments in R&D. Column 6 shows that firm scientific capabilities—as measured by the stock of corporate publications—have a positive relationship with total procurement contracts (p-value < 0.01). Yet, this relationship has been weakening over time, as shown in the negative and significant (p-value < 0.001) interaction coefficient. This result complements Arora et al. (2018), who document a decline in the stock market value and the M&A value of scientific capabilities.

In summary, the evidence presented in this table is consistent with the patterns in Figures 1 and 2. Over time, the composition of government contracts has shifted toward buying products and services with proven commercial markets. Moreover, the importance of scientific capabilities for contract value appears to have fallen.[59] As government procurement emphasized technologies with existing commercial applications, the ability of public demand to substitute for private markets in incentivizing upstream corporate R&D eroded.

6 Discussion and Conclusion

Corporate participation in scientific research can help firms gain access to guaranteed public demand. We provide systematic evidence in support of the government's role in de-risking upstream R&D through guaranteed demand, whereby firms invest in scientific research to increase their chances of winning R&D races as a pathway to downstream product procurement. We present two sets of results. First, we document a positive effect of government contracts on publications ("R") and show that the effect is stronger for larger firms and when private market incentives are relatively weak. Second, we show that the effect was stronger

[58] The specifications in Columns 3 and 5 use data from fiscal years 1994-2015 because the data element that allows us to identify commercial contracts was only introduced following the Federal Acquisition Streamlining Act of 1994.

[59] As Appendix Tables G18 and G19 show, these changes are present across all industries and are robust to considering different firm subsamples and nonlinear time effects.

Table 10: CONTRACTS AND SCIENTIFIC CAPABILITIES OVER TIME

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Contract value		Contract composition		Scientific capabilities	
	ln(All contracts)	ln(R&D contracts)	ln(Comm. contracts)	Share R&D/ All contracts	Share comm./ All contracts	ln(All contracts)	ln(All contracts)
Time trend	0.335	-0.123	2.631	-0.002	0.235	0.480	0.552
	(0.092)	(0.066)	(0.103)	(0.018)	(0.023)	(0.111)	(0.133)
ln(Publications stock)$_{t-1}$						0.542	0.352
						(0.118)	(0.142)
Time trend × ln(Publications stock)$_{t-1}$						-0.113	-0.083
						(0.034)	(0.050)
ln(Patents stock)$_{t-1}$							0.448
							(0.143)
Time trend × ln(Patents stock)$_{t-1}$							-0.063
							(0.052)
ln(R&D stock)$_{t-1}$	0.438	0.147	0.302	0.001	-0.030	0.337	0.231
	(0.058)	(0.037)	(0.060)	(0.007)	(0.018)	(0.061)	(0.066)
Sample years	1980-2015	1980-2015	1995-2015	1980-2015	1995-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	No	No	No	No	No	No	No
Firms	4,367	4,370	3,727	2,129	1,748	4,367	4,367
Observations	52,793	52,866	38,443	22,528	15,960	52,793	52,793
Adjusted R-squared	0.738	0.657	0.672	0.007	0.003	0.739	0.739

Notes: This table presents OLS estimates for changes in procurement contract value, procurement contract composition, and the relationship between total contracts and firm scientific capabilities over time. *Time trend* is divided by 10. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

before the mid-1990s, when policy reforms such as the Federal Acquisition Streamlining Act of 1994 changed the composition of procurement contracts. The government's new emphasis on reducing cost and increasing efficiency and transparency in procurement is evidenced by the rising shares of commercial and competitive contracts.

With the above findings, we make two main contributions. First, we help explain why corporations are withdrawing from scientific research (e.g., Arora et al., 2018, 2021; Mowery, 1998, 2009a). Our results show that firms invest in scientific research to win contracts, yet publications have become less important for public demand, probably due to the government's increased focus on procuring technologies that are proven in commercial markets. Recent studies show that the composition of corporate R&D has shifted away from research and toward development. Specifically, the share of research in business R&D has dropped from a high of 31% in 1986 to just 20% in 2015.[60] Moreover, the annual number of corporate publications has steadily declined since the mid-1990s (Arora et al., 2021). In addition, the

[60]Data are from Tables 2, 3, and 4 of the National Patterns of R&D Resources series (National Center for Science and Engineering Statistics, 2019).

market value attributed to firm scientific capabilities (i.e., the "shadow price" of scientific publications) has also fallen over time (Arora et al., 2018). This means that investors value corporate research less today than in the past. The same pattern holds for managers, who are willing to pay less today for the scientific capabilities of their acquisition targets than in years prior. This paper reinforces these trends by showing that scientific research has fallen out of favor with the U.S. government as well. Once the government began competing with commercial markets, corporations had fewer incentives to perform risky upstream scientific research and more incentives to invest in downstream development of commercially viable products and services. By decoupling R&D contracts from product procurement, the government has potentially amplified the corporate withdrawal from science.

Second, we add to the literature on the effect of government policy on innovation (e.g., Bloom et al., 2019; Edler & Georghiou, 2007; Mowery, 2010; Mowery, Nelson, & Martin, 2010; Rogerson, 1989; Slavtchev & Wiederhold, 2016). Our results show that procurement policy—an area that has not received as much scholarly attention as public funding and tax policies—should also be considered a national innovation policy. Legislative and executive actions, such as the Buy American Act of 1933, have long used procurement contracts to boost domestic economic activity and support targeted geographies or industries. President Biden's Executive Order on Ensuring the Future Is Made in All of America by All of America's Workers, signed January 25, 2021, is just a recent example. Yet, to the best of our knowledge, this paper is the first to estimate the effect of procurement contracts on scientific research and downstream development separately, and the first to investigate the guaranteed demand mechanism. By providing evidence that R&D contracts have a positive effect on corporate scientific research, we advance the understanding of how, and under what conditions, government contracts affect the U.S. innovation ecosystem.

While we document that, on average, publicly traded firms perform more scientific research when they receive procurement contracts, this effect may mask substantial heterogeneity. The R&D race leading up to the production of stealth aircraft exemplifies it (Westwick, 2019). In the 1970s, Northrop Corporation and Lockheed Corporation competed to design and build the first operational stealth aircraft. The main technical challenge was to minimize the diffraction of radar waves after they hit the aircraft's surface. Northrop CEO Tom Jones once remarked "we knew that it was the laws of physics that caused radar to be invented in the first place" (Grant, 2013, p. 5). Understanding those laws eventually led to defeating radar tracking.

In the late 1950s, Soviet physicist Pyotr Ufimtsev had worked on the problem of diffraction, how water, sound, or light waves interact with the edges of an object. Ufimtsev discovered "fringe currents," nonuniform components that helped account for how diffraction happens around corners. This discovery became the basis for stealth aircraft development, but not in the Soviet Union. While the Soviet Defense Ministry showed no interest in Ufimtsev's findings, the U.S. Department of Defense did. During the Cold War, the agency funded the translation of Russian scientific journals to see what they could glean and apply to military programs. Ufimtsev's 1962 book, *Method of Edge Waves in the Physical Theory of Diffraction*, was published in English in 1971.

Both Northrop and Lockheed understood the basic science of radar waves, but not fringe currents. Once they were able to access Ufimtsev's findings, and the mathematical theory and equations that anchored them, firms could begin to design aircraft with minimal radar footprints. Northrop invested heavily in the science behind the Physical Theory of Diffraction, while Lockheed relied on numerical simulations. Northrop radar expert John Cashen remarked "I could see the waves [...] We didn't need a computer program to tell us what the [radar cross section] could be. That was the difference between Northrop and Lockheed" (Grant, 2013, p. 8). Interestingly, Lockheed won the first contract to produce the F-117 stealth fighter, but Northrop won the bigger contract to produce the B-2 stealth bomber because they were able to build planes with curvatures or "big bellies." Northrop was able to predict how waves would behave when they hit curved surfaces due to their deep understanding of diffraction around corners.

To what extent this example is representative of firms' strategic choices in response to R&D races, and the implications of different R&D choices for winning a single or subsequent innovation contest, remain empirical questions and potentially fruitful avenues for future research.

Other promising directions of future research include (i) why corporations decide to work with the government and (ii) the government's strategies to attract the most innovative firms into the public market. The Federal Acquisition Streamlining Act of 1994 aimed to attract nontraditional contractors (e.g., from the growing commercial IT sector) by lowering procurement barriers. Yet, some of the most innovative firms are still not engaged in federal procurement for emerging technologies.[61] As the number of corporations that perform scientific research in-house has been shrinking for decades, the government's access to cutting-edge technologies arguably depends on its ability to attract the remaining performers of science to the procurement market.

Another promising direction for future research would examine the effect of government

[61] For example, in 2017, Google agreed to develop artificial intelligence (AI) for DoD's Project Maven. Amid employee uproar, the company withdrew from the project a year later, vowing not to develop AI for weapons. Microsoft faced employee pushback in 2019 for letting the DoD test its HoloLens augmented-reality headset. Unlike Google, in 2021, Microsoft signed a contract worth up to $21.9 billion to supply the HoloLens to the Army.

procurement on small firms. This effect should operate through two main channels. The first is direct, in the form of procurement policies that target small firms.[62] The second is indirect, in the form of investments by large firms that wish to use startup technology to land lucrative procurement contracts.[63] Studying the implications of procurement on small firms would deepen substantially our understanding of the effect of public demand on the American innovation ecosystem as a whole.

[62]Federal Acquisition Regulation specifies that the government-wide target for small businesses is at least 23% of the total value of all prime contracts awarded each year. Future research could study the vertical coordination between "prime" contractors and subcontractors in the federal supply chain.

[63]For example, in 2011, Lockheed Martin signed a multi-year contract with Canadian startup D-Wave Systems to access the company's quantum annealing technology.

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FOR ONLINE PUBLICATION

Appendix A Federal Procurement Background

Procuring products and services for the U.S. government through an advertised, competitive process goes back as far as the Revolutionary War (Wittie, 2003).[64] In modern times, the Armed Services Procurement Act of 1947 and the Federal Property and Administrative Services Act of 1949 provided comprehensive legislative frameworks for defense and civilian procurement, respectively. Also noteworthy was the Competition in Contracting Act of 1984 that established "full and open competition" as the standard for federal procurement contracts.

A.1 Procurement Process

The U.S. government is composed of three distinct branches—legislative, executive, and judicial—whose powers and duties are executed through 15 cabinet-level executive departments (Agriculture, Commerce, Defense, Education, Energy, Health and Human Services, Homeland Security, Housing and Urban Development, Interior, Justice, Labor, State, Transportation, Treasury, and Veterans Affairs) and hundreds of independent agencies, government corporations, commissions, and committees. For simplicity, we refer to all these organizations as federal agencies.

The U.S. government's procurement process typically begins with acquisition professionals determining a federal agency's requirements for goods and services and the most appropriate method for purchasing them (Congressional Research Service, 2021). In general, solicitations for contracts above $25,000 are posted on the System for Award Management website, SAM.gov.[65] In response, interested firms prepare and submit offers.[66] Agency personnel then evaluate the offers using the source selection method and criteria described in the solicitation, in accordance with Federal Acquisition Regulation.[67] The agency awards a contract to a firm only after determining that the company is responsible, meaning it has adequate resources to perform the contract (financial, organizational, technical skill, production facilities, etc.) as well as a satisfactory record of performance, integrity, and business ethics. The next steps include contract performance and administration (e.g., invoice processing and payments, performance monitoring, and contract modifications), followed by contract closeout.

[64] For example, the Continental Congress passed a resolution on November 20, 1775 to appoint a committee responsible for advertising, receiving proposals, and contracting rations for two new military battalions.

[65] Other procurement methods include using a government purchase card (i.e., a credit card), placing a task or delivery order against an existing contract, or ordering from a General Services Administration schedule. For R&D contracting, firms can also submit unsolicited proposals or compete in government-sponsored challenges and prize competitions.

[66] Firms can also participate in government procurement by serving as subcontractors to "prime" government contractors.

[67] The two primary methods of source selection are sealed bidding and negotiated contracting. The latter is typically used for R&D contracts.

A.2 Policy Changes

During the Cold War (1948-1989), government procurement focused on achieving and sustaining technological superiority for the purpose of national defense (Weiss, 2014). Federal agencies acquired products and services that met government requirements and specifications and were often unproven in commercial markets (Howell et al., 2021). In the case of defense R&D, which represented the majority of R&D contracts, the DoD was often the sole customer (Mowery, 2012). The government's acquisition procedures could be very complex. R&D races were often used to develop new products at the technological leading-edge. Winners were rewarded with noncompetitive product contracts. This incentivized firms to perform upstream science and enabled contractors to mitigate the market risk of performing scientific research that didn't yet have commercial applications.

The composition of procurement contracts began shifting toward dual-use technologies and commercial items in the 1980s and accelerated in the 1990s. Numerous policy changes were made in response to the end of the Cold War, increased global trade, constrained defense budgets, and the need to attract nontraditional, innovative suppliers from the much larger commercial markets, especially those in the growing IT sector (Mowery, 1998; Weiss, 2014). Specifically, the U.S. government implemented sweeping patent and intellectual property reforms, acquisition reforms, and organizational reforms. For example, the Bayh-Dole Act of 1980 and its extensions allowed contractors to retain ownership of inventions made with federal funding. The Stevenson-Wydler Technology Innovation Act of 1980 and its extensions gave businesses access to technologies developed in federal laboratories. The Competition in Contracting Act of 1984 mandated that all procurement contracts be awarded based on full and open competition unless regulatory or statutory exclusions applied. The Goldwater-Nichols Department of Defense Reorganization Act of 1986 reworked the military command structure and implemented shared procurement across the military branches. The Defense Acquisition Workforce Improvement Act of 1990 established education and training standards for government acquisition professionals. The organizational reforms included the creation of new "hybrid" forms of public-private partnering (Weiss, 2014). One example is the SEMATECH industrial consortium, which was formed in 1987 with funding from the Defense Advanced Research Projects Agency and the involvement of 14 American semiconductor manufacturers.

These policy changes culminated in the Federal Acquisition Streamlining Act of 1994, which enabled simplified acquisition procedures and established a statutory preference for government procurement of commercial items (Barry, 1995). Procurement dollars were reallocated *away from* mission-focused technologies that met government specifications and *toward* dual-use technologies that had both government and commercial potential. Driven by pressures to reduce cost and increase efficiency and transparency, the government began competing with the commercial markets for technologies that already had low(er) commercial risk. As a result, corporations had fewer incentives to perform upstream research and more incentives to invest in downstream development of commercially viable products and services.

Appendix B Data Construction

B.1 Collecting Contracts

The U.S. General Services Administration manages the Federal Procurement Data System (FPDS), the central repository of information on U.S. government procurement contracts. The FPDS contains detailed information on all contract transactions above the micro-purchase threshold, which generally ranges from $2,000 to $25,000, depending on the fiscal year, type of award recipient, and place of performance.[68] FPDS also maintains the list of valid contracting offices, including their corresponding agencies and departments.

The Federal Funding Accountability and Transparency Act of 2006 (FFATA) required that federal contract, grant, loan, and other financial assistance awards of more than $25,000 be displayed on a publicly accessible website.[69] In response, the U.S. Department of the Treasury developed USAspending.gov as the official public source of federal government contract data (pulled from FPDS) and grant, loan, and other financial assistance data (reported to the Data Act Broker managed by the U.S. Department of the Treasury). The "Custom Award Data" section of the USAspending.gov website allows the public to view and download award transactions for fiscal years starting in 2001.[70] We used it to download .csv files containing transactions for all prime procurement contracts, awarded by all federal agencies, for all locations, during fiscal years 2001-2020.[71]

We supplemented these data with historical contract transactions from beta.SAM.gov, a website managed by the General Services Administration. The website allows the public to download FPDS award transactions after creating user accounts. We used it to download .csv files containing prime award transactions for procurement contracts awarded by all federal agencies for all locations during fiscal years 1980-2000.

To identify the government entity that awarded each procurement contract, acquisition professionals use a four-digit Awarding Agency ID.[72] The FPDS provides a list of 6,725 contracting offices that were active and valid as of November 2, 2020 (Federal Procurement Data System, 2021). These offices are grouped into 227 agencies that are subordinated to 99 first-level "departments." We link each Awarding Agency ID to the corresponding first-level department. Our resulting dataset contains 81.9 million transactions for procurement

[68] Other exceptions to the reporting rule include classified contracts, as well as contracts that contain sensitive information about recipients, locations, and operations. For obvious reasons, we cannot estimate the precise value of these unreported contracts.

[69] FFATA was amended by the Government Funding Transparency Act of 2008, which required prime contractors to report details on their first-tier subcontractors and expanded with the Digital Accountability and Transparency Act of 2014, which established government-wide financial data standards (USAspending.gov, 2021a).

[70] An award usually is made up of a series of transactions, which include the initial award and any subsequent modifications, such as additions or continuations of funding and changes to the scope of work (USAspending.gov, 2020).

[71] Award types include prime awards for contracts, contract indefinite delivery vehicles (IDV), grants, direct payments, loans, insurance, and other financial assistance (USAspending.gov, 2021c).

[72] The data also include information about the awarding department/office and funding department/agency/office. However, the procurement contracts are uniquely identified—using the Procurement Instrument Identifier or PIID—at the awarding agency level. Therefore, we use the awarding agency as the primary data element for classifying contracts by source.

contracts awarded during fiscal years 1980-2015 by 72 different federal agencies.[73] As can be seen in Table B1, 12% of the $12.5 trillion in procurement contracts were for R&D services.

The federal government reports *obligations* for procurement contracts, not actual *outlays*. An obligation is the government's promise to spend funds (immediately or later) as a result of entering into a contract, so long as the agreed-to actions take place. An outlay takes place when those funds are actually paid out to the contractor (Datalab, 2018). If the entire amount initially obligated is not used, the last modification will display a negative dollar amount. For example, if an initial contract award was for $100,000 and an agency only used $90,000 of that initial obligation, the last transaction associated with the award would display an amount of -$10,000 (Datalab, 2018).

B.2 Matching Contracts to Firms

We merged the contract data with the panel of U.S.-headquartered publicly traded firms from Arora et al. (2021). We string-matched more than 1.7 million contractor names (including recipients and their parent companies) against almost 60,000 firm names (including ultimate owners and their subsidiaries).[74] Specifically, we used *matchit*, a Stata tool that can join observations from two datasets based on string variables that are not exactly the same (Raffo, 2020), to perform vectoral decomposition of firm names using five-character grams. Then, we applied Jaccard similarity scoring. For each contractor, we retained the five best potential matches (in decreasing order of similarity score, as long as the score was above 0.5) and completed a four-step process to clean them.

Step 1. We removed unicode and special characters, as well as legal suffixes (e.g., inc, corp, ltd) and conjunctions (e.g., and, on, at) from names, generating "core" versions of contractor and firm names. We reapplied the *matchit* tool to evaluate the quality of the match between these "core" names. This time, we used bigrams in the vectoral decomposition and dropped potential "core" matches that had a Jaccard similarity score below 0.65.

Step 2. We removed generic words from firm names (e.g., terms describing an industry or activity), generating "nongeneric" versions of contractor and firm names. We reapplied the *matchit* tool to evaluate the quality of the match between these "nongeneric" names. We used bigrams in the vectoral decomposition and dropped potential "nongeneric" matches that had a Jaccard similarity score below 0.65.

Step 3. We calculated the Levenshtein distance between "nongeneric" names, and dropped potential matches with an edit distance greater than 15. For each contractor, we retained only the best potential match (in decreasing order of "core" and "nongeneric" similarity scores).

Step 4. We manually cleaned potential matches that had similarity scores below 0.9, discarding any obvious mismatches.

We obtained a dataset of 37,506 contractors matched to 12,510 ultimate owner and

[73] Transactions where the Awarding Agency ID (i) was missing or (ii) did not match any of the active agencies were grouped under the "Other" category. For example, the Tennessee Valley Authority is a wholly owned government corporation; while it awarded procurement contracts during 1980-2015, it isn't included in the November 2, 2020, list of active agencies.

[74] We standardized recipient names using the same code used by Arora et al. (2021) to identify the best possible matches to the panel of firms.

Table B1: Agencies That Awarded Contracts During 1980-2015

Federal agency	All contracts ($ mm)	Share R&D / All contracts	Share matched to firm panel
Defense, Department of	8,621,394	13%	56%
Air Force	2,108,521	21%	70%
Navy	2,578,467	14%	70%
Army	2,527,795	10%	42%
Missile Defense Agency (MDA)	83,913	45%	97%
Defense Threat Reduction Agency (DTRA)	23,791	57%	46%
Defense Adv. Res. Proj. Agency (DARPA)	13,895	91%	59%
Other DoD	1,285,012	1%	27%
Energy, Department of	933,972	7%	34%
National Aeronautics and Space Admin.	489,721	41%	67%
General Services Administration	296,698	<1%	24%
Health and Human Services, Department of	271,837	19%	32%
Veterans Affairs, Department of	267,241	<1%	33%
Homeland Security, Department of	170,631	5%	31%
Transportation, Department of	130,353	13%	32%
Treasury, Department of the	128,966	1%	17%
Justice, Department of	128,115	2%	21%
State, Department of	112,745	1%	25%
Interior, Department of the	100,230	5%	14%
Agriculture, Department of	86,328	1%	21%
Agency for International Development	61,025	7%	14%
Commerce, Department of	55,155	5%	30%
Labor, Department of	49,668	1%	10%
Environmental Protection Agency	40,987	6%	15%
Education, Department of	36,075	7%	24%
Office of Personnel Management	26,331	<1%	9%
Housing and Urban Development, Dept. of	24,869	4%	22%
Social Security Administration	20,111	<1%	44%
National Science Foundation	10,105	28%	30%
Smithsonian Institution	5,308	2%	5%
Nuclear Regulatory Commission	4,300	10%	26%
Securities and Exchange Commission	3,286	1%	28%
Pension Benefit Guaranty Corporation	3,177	<1%	16%
National Archives and Records Admin.	2,955	<1%	27%
Small Business Administration	2,075	1%	22%
Peace Corps	1,893	14%	12%
United States Agency for Global Media, BBG	1,764	<1%	18%
Equal Employment Opportunity Commission	1,676	<1%	7%
Federal Communications Commission	1,258	1%	11%
Executive Office of the President	1,175	1%	36%
Federal Trade Commission	822	1%	34%
Corp. for National and Community Service	788	3%	8%
Millennium Challenge Corporation	773	14%	7%
National Labor Relations Board	748	<1%	73%
Intl. Boundary and Water Commission: U.S.-Mexico	609	11%	4%
Commodity Futures Trading Commission	516	<1%	47%
Railroad Retirement Board	452	<1%	22%
National Gallery of Art	394	38%	2%
Government Accountability Office	382	10%	8%

Notes: This table displays federal agencies that awarded procurement contracts during fiscal years 1980-2015. Contracts are deflated using the GDP Implicit Price Deflator to reflect constant 2012 dollars (in millions) (U.S. Bureau of Economic Analysis, 2021).

Table B1: Agencies That Awarded Contracts During 1980-2015 (Continued)

Federal agency	All contracts ($ mm)	Share R&D / All contracts	Share matched to firm panel
Consumer Product Safety Commission	365	2%	12%
Court Services and Offender Supervision Agency	346	8%	7%
J. F. Kennedy Center for the Performing Arts	248	<1%	3%
Consumer Financial Protection Bureau	214	0%	7%
National Transportation Safety Board	128	1%	30%
United States Trade and Development Agency	125	54%	4%
Federal Election Commission	119	1%	11%
Export-Import Bank of the U.S.	109	2%	6%
International Trade Commission	108	<1%	12%
Overseas Private Investment Corporation	90	1%	6%
National Mediation Board	71	0%	5%
National Endowment for the Humanities	66	<1%	12%
Merit Systems Protection Board	45	8%	12%
Defense Nuclear Facilities Safety Board	44	10%	3%
Federal Housing Finance Agency	29	<1%	4%
National Endowment for the Arts	27	2%	7%
Selective Service System	25	0%	11%
The Institute of Museum and Library Services	17	<1%	7%
Federal Maritime Commission	15	<1%	34%
Federal Mediation and Conciliation Service	15	5%	9%
Armed Forces Retirement Home	14	0%	0%
Federal Labor Relations Authority	9	1%	17%
National Capital Planning Commission	8	2%	3%
Chemical Safety and Hazard Investigation Board	7	0%	8%
Occupational Safety and Health Review Commission	5	16%	17%
Committee for Purchase From People Who Are Blind or Severely Disabled	4	0%	9%
Election Assistance Commission	2	24%	16%
Office of Special Counsel	2	27%	42%
Library of Congress	2	0%	28%
American Battle Monuments Commission	0	0%	50%
Other	357,695	4%	22%
Total	12,456,862	12%	49%

Notes: This table displays federal agencies that awarded procurement contracts during fiscal years 1980-2015. The "Other" category identifies contracts where the awarding federal agency is (i) not identified in the FPDS data or (ii) no longer active as of December 2020. Contracts are deflated using the GDP Implicit Price Deflator to reflect constant 2012 dollars (in millions) (U.S. Bureau of Economic Analysis, 2021).

subsidiary names. Overall, we matched 49% of all procurement contracts awarded during 1980-2015 to our sample of publicly traded, R&D performing, U.S.-headquartered firms. We aggregated contracts by firm-year, then allocated contracts matched to subsidiaries to the appropriate ultimate owners using the dynamic match produced by Arora et al. (2021). In summary, we identified 2,568 firms (i.e., ultimate owners) that received a total of $5.9 trillion in procurement contract obligations during 1980-2015. Table H25 presents the distribution by two-digit SIC code, while Table H20 displays the largest contractors (by total value of contracts won) in each decade covered by our sample.

Appendix C Variable Construction

Table C3 includes definitions and sources for all the variables used in our econometric analyses. The steps used to split procurement contracts into various types (e.g., R&D vs. non-R&D), assign contracts to industries, and create variables for several characteristics of science are detailed below.

C.1 Contract Variables

The types and names of data fields collected in the Federal Procurement Data System (FPDS) have changed over our sample period. For example, prime award data include 169 variables for fiscal years 1980-2000 and 282 variables for fiscal years 2001-2020. To ensure comparability of our analyses over time, we manually mapped the variables obtained from beta.SAM.gov against the corresponding variables obtained from USAspending.gov. To do so, we used the Data Dictionary Crosswalk available from USAspending.gov, as well as the FPDS-NG User's Manual (version 1.5, issued in October 2020) and the FPDS-NG Data Element Dictionary (version 1.5, issued in August 2020) available from FPDS.gov. Table C2 displays the resulting crosswalk between variables.

To describe the products and services acquired in each procurement award, agencies use four-digit Product and Service Codes (PSC) that mirror the Federal Supply Classification (FSC) codes.[75] Currently, the PSC/FSC classification consists of 24 service categories (see Table C4) and 78 product groups (see Table C5). The product groups are further subdivided into 645 classes, as defined in the FPDS Product and Service Codes Manual (U.S. General Services Administration, 2021).

We link the PSC/FSC classification to NAICS industries using the crosswalk from the U.S. Defense Logistics Agency (2020), and then link NAICS industries to SIC industries using the concordances available from the U.S. Census Bureau (2019). This allows us to identify the SIC4 industry for 68% of procurement contract dollars awarded between 1980 and 2015.

We use the *Product or service code* field to split all contracts into R&D contracts (service codes starting with the letter A) vs. non-R&D contracts (service codes starting with letters B through Z and product codes starting with any number).[76] In the procurement contract data, codes for R&D services are composed of two alphabetic and two numeric digits:

- 1st digit: always the letter A to identify R&D services,
- 2nd digit: alphabetic A to Z to identify the major category,
- 3rd digit: numeric 1 to 9 to identify a subdivision of the major category, and
- 4th digit: numeric 1 to 7 to identify the appropriate stage of R&D:
    1. Basic research,

[75] The FSC is a government-wide commodity classification system designed for grouping, classifying, and naming all personal property items (U.S. Defense Logistics Agency, 2003).

[76] When a contract action includes more than a single product or service, the awarding agency uses the code corresponding to the predominant product or service.

Table C2: Variable Crosswalk

beta.SAM.gov variable	USAspending.gov variable	Description
contractingagencyid	awarding_sub_agency_code	Awarding Agency ID
contractingagencyname	awarding_sub_agency_name	Awarding Agency Name
contractingofficeid	awarding_office_code	Awarding Office ID
contractingofficename	awarding_office_name	Awarding Office Name
fundingdepartmentid	funding_agency_code	Funding Department ID
fundingdepartmentname	funding_agency_name	Funding Department Name
fundingagencyid	funding_sub_agency_code	Funding Agency ID
fundingofficeid	funding_office_code	Funding Office ID
piid	award_id_piid	PIID
transactionnumber	transaction_number	Transaction Number
modificationnumber	modification_number	Modification Number
reasonformodification	action_type_code	Reason for Modification
referencedidvpiid	parent_award_id_piid	Parent Award ID
datesigned	action_date	Date Signed/Action Date
actionobligation	federal_action_obligation	Action Obligation
baseandalloptionsvaluetotal contr	base_and_all_options_value	Base and All Options Value
baseandexercisedoptionsvalue	base_and_exercised_options_value	Base and Exercised Options Value
vendorname	recipient_name	Recipient Name
dunsnumber	recipient_duns	Recipient DUNS
globalvendorname	recipient_parent_name	Recipient Parent Name
globaldunsnumber	recipient_parent_duns	Recipient Parent DUNS
naicscode	naics_code	NAICS Code
naicsdescription	naics_description	NAICS Description
periodofperformancestartdate	period_of_performance_start_date	Period of Performance Start Date
estultimatecompletiondate	period_of_performance_potential_	Est. Ultimate Completion Date
lastdatetoorder	ordering_period_end_date	Last Date to Order
completiondate	period_of_performance_current_en	Completion Date
productorservicecode	product_or_service_code	Product or Service Code
descriptionofrequirement	award_description	Description of Requirement/Award Description
awardtype	award_type_code	Award Type
typeofcontract	type_of_contract_pricing_code	Type of Contract
commercialitemacquisition procedu	commercial_item_acquisition_proc	Commercial Item Acquisition Procedures
extentcompeted	extent_competed_code	Extent Competed
otherthanfullandopen competition	other_than_full_and_open_competi	Other Than Full and Open Competition
domesticorforeignentity	domestic_or_foreign_entity_code	Domestic or Foreign Entity
evaluatedpreference	evaluated_preference_code	Evaluated Preference
fairopportunitylimitedsources	fair_opportunity_limited_sources	Fair Opportunity/Limited Sources
foreignfunding	foreign_funding	Foreign Funding
inherentlygovernmentalfunction	inherently_governmental_function	Inherently Governmental Function
isperformancebasedserviceacquisi	performance_based_service_acquis	Is Performance Based Service Acquisition
localareasetaside	local_area_set_aside_code	Local Area Set Aside
numberofactions	number_of_actions	Number of Actions
samexceptiontype	sam_exception	SAM Exception Type
solicitationprocedures	solicitation_procedures_code	Solicitation Procedures
typeofsetaside	type_of_set_aside	Type of Set Aside
typeofsetasidesource	type_of_set_aside_code	Type of Set Aside Source

Notes: This table displays a crosswalk between contract variables available for 1980-2000 from beta.SAM.gov and variables available for 2001-2020 from USAspending.gov.

2. Applied research and exploratory development,
3. Advanced development,
4. Engineering development,
5. Operational systems development,
6. Management and support, and
7. Commercialization (U.S. General Services Administration, 2021).

We use these patterns to split R&D contracts into research contracts vs. development contracts. Specifically, we code the first two stages of R&D (i.e., Basic research and Applied research and exploratory development) as *R contracts*, and the other five stages as *D contracts*. We further divide non-R&D contracts into non-R&D service contracts vs. product contracts.

Table C3: Variable Definitions

Variable	Definition	Source
Publications	Sum of scholarly, peer-reviewed publications that have at least one author affiliated with the focal firm and were published in the focal year. Appendix C details how we split the publication flow into *Internal use* vs. *No internal use* (to capture the focal firm's own use of science), *Low rival use* vs. *High rival use* (to capture product-market rivals' use of science), and *High protection publications* vs. *Low protection publications* (to capture the scope of protection offered by the focal firm's own patents).	Clarivate Analytics' Web of Science (Arora et al., 2021)
Publications stock	Calculated using a perpetual inventory method with a 15% depreciation rate (Hall et al., 2005), such that the stock in year t is $Publications\ stock_t = Publications_t + (1-\delta) Publications\ stock_{t-1}$, where $\delta = 0.15$.	
Patents	Sum of patents granted by the U.S. Patent and Trademark Office to the focal firm in the focal year.	European Patent Office's PATSTAT database (Arora et al., 2021)
All contracts	Sum of all contract awards associated with a firm-year ($ mm).	USAspending.gov, beta.SAM.gov
R&D contracts	Sum of R&D contract awards associated with a firm-year ($ mm).	
Non-R&D contracts	Sum of non-R&D contract awards associated with a firm-year ($ mm).	
R contracts	Sum of research contract awards associated with a firm-year ($ mm).	
D contracts	Sum of development contract awards associated with a firm-year ($ mm).	
Commercial contracts	Sum of commercial contract awards associated with a firm-year ($ mm).	
Noncommercial contracts	Sum of noncommercial contract awards associated with a firm-year ($ mm).	
All grants	Sum of all project grants and cooperative agreements associated with a firm-year ($ mm)	USAspending.gov
Time trend	Focal year minus 1980 (in decennial units).	
Sales	Sales for the focal firm-year ($ mm).	Standard & Poor's Compustat North America (Arora et al., 2021)
R&D expenditures	R&D expenditures for the focal firm-year ($ mm).	Standard & Poor's Compustat North America (Arora et al., 2021)
R&D stock	Calculated using a perpetual inventory method with a 15% depreciation rate, such that the stock in year t is $R\&D\ stock_t = R\&D\ expenditures_t + (1-\delta) R\&D\ stock_{t-1}$, where the focal firm's *R&D expenditures* in year t are based on Compustat data and $\delta = 0.15$. Expressed in $ mm.	Standard & Poor's Compustat North America (Arora et al., 2021)
Industry R&D funding	Calculated by multiplying the level of R&D contracts obligated to the focal firm's SIC3 industry (not including the contracts obligated to the focal firm that year) times the share of R&D contracts obligated to the focal firm's SIC4 industry (averaged over the sample period of 1980-2015). Expressed in $ mm.	USAspending.gov, beta.SAM.gov
Cold War shock	Calculated using the difference in average contract values between pre (1986-1988) and post (1990-1992) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries. Expressed in $ mm. The sales exposure is calculated as the share of the focal firm's sales during 1982-1985 that came from each SIC4 industry.	USAspending.gov, beta.SAM.gov, Standard & Poor's Compustat North America
Global War on Terrorism shock	Calculated using the difference in contract values between pre (2000) and post (2004) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries. Expressed in $ mm. The sales exposure is calculated as the share of the focal firm's sales during 1994-1997 that came from each SIC4 industry.	USAspending.gov, beta.SAM.gov, Standard & Poor's Compustat North America
Financial Crisis shock	Calculated using the difference in contract values between pre (2007) and post (2008) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries. Expressed in $ mm. The sales exposure is calculated as the share of the focal firm's sales during 2000-2003 that came from each SIC4 industry.	USAspending.gov, beta.SAM.gov, Standard & Poor's Compustat North America

Notes: This table displays definitions and sources for the variables used in our econometric analyses. Dollar values are deflated using the GDP Implicit Price Deflator to reflect constant 2012 dollars (U.S. Bureau of Economic Analysis, 2021).

We use the *Commercial items acquisition procedures* field to split non-R&D contracts into commercial contracts vs. noncommercial contracts.[77] Contracts were awarded using com-

[77] This field indicates whether the solicitation used the special requirements for the acquisition of commer-

Table C3: Variable Definitions (Continued)

Variable	Definition	Source
Cold War shock	Calculated using the difference in average contract values between pre (1986-1988) and post (1990-1992) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries. Expressed in $ mm. The sales exposure is calculated as the share of the focal firm's sales during 1982-1985 that came from each SIC4 industry.	USAspending.gov, beta.SAM.gov, Standard & Poor's Compustat North America
Global War on Terrorism shock	Calculated using the difference in contract values between pre (2000) and post (2004) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries. Expressed in $ mm. The sales exposure is calculated as the share of the focal firm's sales during 1994-1997 that came from each SIC4 industry.	USAspending.gov, beta.SAM.gov, Standard & Poor's Compustat North America
Financial Crisis shock	Calculated using the difference in contract values between pre (2007) and post (2008) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries. Expressed in $ mm. The sales exposure is calculated as the share of the focal firm's sales during 2000-2003 that came from each SIC4 industry.	USAspending.gov, beta.SAM.gov, Standard & Poor's Compustat North America

Notes: This table displays definitions and sources for the variables used in our econometric analyses. Dollar values are deflated using the GDP Implicit Price Deflator to reflect constant 2012 dollars (U.S. Bureau of Economic Analysis, 2021).

mercial item procedures only after the passage of the Federal Acquisition Streamlining Act of 1994. Therefore, our data separating commercial vs. noncommercial contracts only span fiscal years 1994-2015. While some R&D service contracts were awarded using streamlined commercial item procedures, they represent less than 1% of the value of all R&D contracts awarded to sample firms. Therefore, we do not break down R&D contracts into commercial vs. noncommercial contracts.

We use the *Extent competed* field to distinguish contracts that were awarded competitively from those awarded noncompetitively. In general, federal agencies are required to use full and open competition when awarding procurement contracts (U.S. Government Accountability Office, 2014). Competitive procedures include sealed bids, competitive proposals, or a combination of competitive procedures. However, the Competition in Contracting Act of 1984 authorized noncompetitive contracting under certain conditions.[78] We aggregate competed and total contracts by year and contract type to produce the trend lines in Figure 3.

cial items, supplies, or services. Those requirements are intended to more closely resemble the commercial markets as defined by Federal Acquisition Regulation Part 12 (Federal Procurement Data System, 2020).

[78]Federal Acquisition Regulation currently identifies seven exceptions to full and open competition: (i) only one responsible source and no other supplies or services will satisfy agency requirements; (ii) unusual and compelling urgency; (iii) industrial mobilization; engineering, developmental, or research capability; or expert services; (iv) international agreement; (v) authorized or required by statute; (vi) national security; and (vii) public interest (Federal Acquisition Regulation, 2019).

Table C4: Classification Codes for Services

Code	Service category	Code	Service category
A	Research and development	N	Installation of equipment
B	Special studies and analyses – not R&D	P	Salvage services
C	Architect and engineering services – construction	Q	Medical services
D	Automatic data processing and telecommunication services	R	Professional, administrative and management support services
E	Purchase of structures and facilities	S	Utilities and housekeeping services
F	Natural resources and conservation services	T	Photographic, mapping, printing, and publications services
G	Social services	U	Education and training services
H	Quality control, testing, and inspection services	V	Transportation, travel and relocation services
I	Maintenance, repair and rebuilding of equipment	W	Lease or rental of equipment
K	Modification of equipment	X	Lease or rental of facilities
L	Technical representative services	Y	Construction of structures and facilities
M	Operation of government owned facility	Z	Maintenance, repair or alteration of real property

Notes: This table displays the 24 high-level categories used to classify the services purchased by the federal government.

Table C5: Classification Codes for Products

Code	Product group	Code	Product group
10	Weapons	53	Hardware and Abrasives
11	Nuclear Ordinance	54	Prefabricated Structures and Scaffolding
12	Fire Control Equipment	55	Lumber, Millwork, Plywood, and Veneer
13	Ammunition and Explosives	56	Construction and Building Materials
14	Guided Missiles	58	Communications, Detection and Coherent Radiation Equipment
15	Aircraft and Airframe Structural Components	59	Electrical and Electronic Equipment Components
16	Aerospace Craft Components and Accessories	60	Fiber Optics Materials and Components, Assemblies and Accessories
17	Aerospace Craft Launching, Landing, and Ground Handling Equipment	61	Electric Wire, and Power and Distribution Equipment
18	Space Vehicles	62	Lighting Fixtures and Lamps
19	Ships, Small Craft, Pontoons, and Floating Docks	63	Alarm, Signal and Security Detection Systems
20	Ship and Marine Equipment	65	Medical, Dental, and Veterinary Equipment and Supplies
22	Railway Equipment	66	Instruments and Laboratory Equipment
23	Ground Effect Vehicles, Motor Vehicles, Trailers, and Cycles	67	Photographic Equipment
24	Tractors	68	Chemicals and Chemical Products
25	Vehicular Equipment Components	69	Training Aids and Devices
26	Tires and Tubes	70	ADP Equipment Software, Supplies and Support Equipment
28	Engines, Turbines, and Components	71	Furniture
29	Engine Accessories	72	Household and Commercial Furnishings and Appliances
30	Mechanical Power Transmission Equipment	73	Food Preparation and Serving Equipment
31	Bearings	74	Office Machines
32	Woodworking Machinery and Equipment	75	Office Supplies and Devices
34	Metalworking Machinery	76	Books, Maps, and Other Publications
35	Service and Trade Equipment	77	Musical Instruments, Phonographs, and Home Radios
36	Special Industry Machinery	78	Recreational and Athletic Equipment
37	Agricultural Machinery and Equipment	79	Cleaning Equipment and Supplies
38	Construction, Mining, Excavating, and Highway Maintenance Equipment	80	Brushes, Paints, Sealers, and Adhesives
39	Materials Handling Equipment	81	Containers, Packaging, and Packing Supplies
40	Rope, Cable, Chain, and Fittings	83	Textiles, Leather, Furs, Apparel and Shoes, Tents, Flags
41	Refrigeration, Air Conditioning and Air Circulating Equipment	84	Clothing, Individual Equipment, and Insignia
42	Fire Fighting, Rescue, and Safety Equipment	85	Toiletries
43	Pumps and Compressors	87	Agricultural Supplies
44	Furnace, Steam Plant, and Drying Equip, Nuclear Reactors	88	Live Animals
45	Plumbing, Heating and Sanitation Equipment	89	Subsistence (Food)
46	Water Purification and Sewage Treatment Equipment	91	Fuels, Lubricants, Oils, and Waxes
47	Pipe, Tubing, Hose, and Fittings	93	Nonmetallic Fabricated Materials
48	Valves	94	Nonmetallic Crude Materials
49	Maintenance and Repair Shop Equipment	95	Metal Bars, Sheets, and Shapes
51	Hand Tools	96	Ores, Minerals, and Their Primary Products
52	Measuring Tools	99	Miscellaneous

Notes: This table displays the 78 high-level groups used to classify the products purchased by the federal government. Groups 21, 27, 33, 50, 57, 64, 82, 86, 90, 92, 97, and 98 are currently unassigned.

C.2 Private Market Incentives Variables

We measure several characteristics of corporate science that allow us to estimate the effect of procurement contracts on corporate R&D under different private market conditions.

First, we split the annual publication flow into (i) publications cited by the firm's own patents and (ii) publications not cited by the firm's own patents. We use the non-patent literature citations file from Arora et al. (2021) to do so. The number of unique publications that receive one or more citations from the firm's own patents is aggregated at the firm-year level into the variable *Internal use publications*. The remaining annual publication flow is captured in the variable *No internal use publications*.

Second, we identify publications that are cited by one or more patents assigned to other panel firms. We split this annual publication flow into (i) publications with low rival use and (ii) publications with high rival use. To do so, we use a measure of the product-market rivalry between the publishing firm and the patenting firms (up to three corporate assignees per patent) sourced from Arora et al. (2021). Product-market rivalry is calculated as the Mahalanobis similarity of vectors representing the shares of industry segment sales for each pair of firms. A publication has high rival use if its highest similarity score is in the top quartile of the distribution of similarity scores. The number of unique publications that have high rival use is aggregated at the firm-year level into the variable *High rival use publications*. The remaining annual publication flow is captured in the variable *Low rival use publications*.

Third, we split the annual publication flow into (i) publications that have low patent protection and (ii) publications that have high patent protection. We measure the textual proximity of publications (abstract and title) to patents (claims) for all Web of Science publications and USPTO patents for our sample period using a three-step procedure.

Step 1: Bag of words. We extract all words from the claims text of patents, as well as the titles and abstracts of publications. For each document (patent or publication), we create a vector of all word stems. Each word stem is weighted by the inverse of its frequency in the complete patent corpus. For each word in a patent, we create an inverse frequency index as:

$$I_i = N_i \times (1 - \frac{p_i}{P})$$

where N_i is the number of times the ith word stem appears throughout the claims section of patents, p_i is the number of patent documents that contain the ith word stem, and P is the number of patents issued by the USPTO. Each item in the index represents the weight assigned to extracted word stems according to their specificity across all USPTO patent documents. We follow the same procedure for the title and abstract of publications (we treat a publication record as a patent document).

An important part of the word stemming process is mapping acronyms and technical concepts. For example, the acronym RAM refers to random access memory. Thus, in our textual comparison algorithm, when the sequence of words "random access memory" appears, we collapse it into RAM. Acronyms appear in capital letters on patent documents. We retain all words with at least two capital letters and manually search for their meaning. To mitigate cases where an acronym has multiple meanings, we perform the acronym-meaning match at the four-digit IPC level. (Chemical compounds also appear in capital letters, but we leave them unchanged.)

Step 2: Distance between words. Similar ideas might be described using different text. Thus, a major challenge is how to compute the "technical distance" between two words. To address it, we develop a dictionary that aims to measure the probability that two distinct words refer to the same technical concept. We identify words used in patent documents deemed to be technically similar by patent examiners.

Specifically, we extract a random sample of about 150,000 non-final rejection letters from the USPTO's Public PAIR (Patent Application Information Retrieval) system. We include only rejections pertaining to novelty or non-obviousness, as outlined in 35 U.S.C. 102 and 35 U.S.C. 103 of the USPTO Manual of Patent Examining Procedure. We extract the text of the original patent application associated with a rejection, as well as the text of the prior-art patents cited as the reason for the rejection. When multiple rejections are associated with the same application, we extract the relevant (modified) application claims for each rejection.

Next, we extract all relevant word stems from the claims section of the focal patent application and corresponding prior-art patents.[79] Then, we calculate the proximity between each pair of word stems based on their co-occurrence. To account for the baseline tendency of two word stems to co-occur across two documents, for each rejected application and rejection prior-art patent pair, we construct a control pair by linking the rejected application with a control patent that was not cited as a reason for the rejection but is in the same 4-digit IPC and has the same application year as the rejection prior-art patent. Proximity between word stems is calculated as the ratio of the number of times the pair appears in the rejected application and rejection prior-art patent to the number of times it appears in the rejected application and the control prior-art patent:

$$Proximity_{w1,w2} = \frac{(A \bigcup R)_{w1,w2}}{(A \bigcup C)_{w1,w2}}$$

$(A \bigcup R)_{w1,w2}$ is the number of times the words $w1$ and $w2$ co-occur within the focal application A and rejection prior-art patent R. $(A \bigcup C)_{w1,w2}$ is the number of times the words $w1$ and $w2$ co-occur in the focal application A and control patent C. Because the same word stem pair, $w1$ and $w2$, can co-occur in more than one application and rejection prior-art patent pair, we average the proximity scores between $w1$ and $w2$ across all application and rejection prior-art patent pairs, denoted by $\bar{P}_{w1_i,w2_i}$.

Step 3: Textual overlap between documents. We construct a similarity score between a pair of documents (i.e., a publication and a patent) based on the "technical distance" between their words. We create a vector of words for each document with their corresponding weights (i.e., inverse frequency) as described in step 1. Then, we calculate the cosine proximity score between the two word vectors $W1$ and $W2$, each vector consisting of n elements, while taking into account the average word pair proximity $\bar{P}_{w1_i,w2_i}$ calculated in step 2:

$$PS_{W1,W2} = \frac{\sum_{i=1}^{i=n} W1_i \times W2_i \times \bar{P}_{w1_i,w2_i}}{\sqrt{\sum_{i=1}^{i=n} W1_i^2}\sqrt{\sum_{i=1}^{i=n} W2_i^2}}$$

[79] We use original applications rather than final patent documents because claims can change during the patent examination process.

We normalize the proximity score $PS_{W1,W2}$ to be between 0 and 1 by dividing it by $\max(PS_{W1_i,W2_i})$. As a result, 1 indicates the highest possible similarity and 0 indicates the lowest possible similarity between two documents.

For each publication between 1980 and 2015, we retain up to five of the highest proximity scores with granted patents. We identify which of those patents are owned by the publishing firm and retain the top matching publication-patent pair. Publications with proximity scores above the median (relative to the publication year) are coded as "protected" by a patent, while those with scores below the median and those unmatched to firm patents are coded as "unprotected" by a patent.[80] The number of unique publications that are "protected" by the firm's patents is aggregated at the firm-year level into the variable *High protection publications*. The remaining annual publication flow is captured in the variable *Low protection publications*.

[80] Our choice of cutoff—the median publication-patent proximity score for all the publications published by sample firms in a given year—allows us to take into consideration how the proximity between publications and patents changes over time.

Appendix D Instrumental Variable Estimation

D.1 Industry R&D Funding

Our first instrument exploits variation in aggregate industry R&D contracts to predict R&D contracts awarded to a focal firm. It is important to recognize that R&D contracts awarded to a firm's SIC4 industry may still be endogenous. To mitigate this concern, we take advantage of changes in R&D funding at a higher level of aggregation, the firm's SIC3 industry. We "distribute" these changes across SIC4 industries according to time-invariant industry shares, closely following Moretti et al. (2021).

We construct our instrumental variable (IV) in three stages. First, we identify the SIC4 industry for each procurement contract awarded during 1980-2015 (not just those matched to sample firms). For transactions that do not list the recipient firm's NAICS code, we use the *Product or service code* (PSC) field and the PSC-to-NAICS crosswalk from U.S. Defense Logistics Agency (2020) to identify the NAICS code. Then, we use the NAICS-to-SIC concordances available from the U.S. Census Bureau (2019) to identify the SIC4 code. We aggregate all R&D contracts awarded to all firms (not just our panel firms) at the SIC4-year and SIC3-year levels, respectively.

Second, we calculate the share of R&D contracts awarded to the SIC4 industry relative to the R&D contracts awarded to the SIC3 industry that contains it. Specifically, we divide the total value of R&D contracts awarded to the SIC4 industry during 1980-2015 by the total value of R&D contracts awarded to the higher-level SIC3 industry during 1980-2015.

Third, we calculate the instrument as $Industry\ R\&D\ funding_{i,t} = (Industry\ R\&D\ contracts_{SIC3,t} - Firm\ R\&D\ contracts_{i,t}) \times Industry\ share_{SIC4,SIC3}$. $Industry\ R\&D\ contracts_{SIC3,t}$ is the total value of all R&D contracts awarded by federal agencies to the focal firm's SIC3 industry in year t. $Firm\ R\&D\ contracts_{i,t}$ is the value R&D contracts awarded to the focal firm in year t. The reason for excluding firm R&D contracts from the construction of the IV is to avoid a mechanical correlation between the endogenous variable we want to instrument and the instrument itself. $Industry\ share_{SIC4,SIC3}$ is calculated by dividing the total value of R&D contracts awarded to the focal firm's SIC4 industry during 1980-2015 by the total value of R&D contracts awarded to the focal firm's higher-level SIC3 industry during 1980-2015. We use a time-invariant share because it allows us to smooth out year-to-year variation in the R&D contracts awarded to the SIC4 industry.

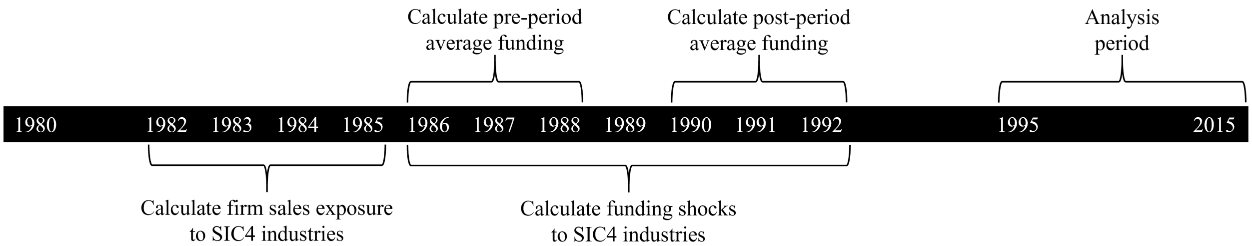
Take Boeing as an example. In 2012, Boeing's SIC3 industry ("372 Aircraft and parts") received $13.7 billion in R&D contracts, including almost $3.6 billion for Boeing. Over the sample period of 1980-2015, Boeing's SIC4 industry ("3721 Aircraft") received 99% of the R&D contracts awarded to its SIC3 industry ("372 Aircraft and parts"). The instrument for Boeing in 2012 was calculated as $(13.7 - 3.6) \times .99 = 10$ (in $ billions).

Using this industry R&D funding measure (rather than the total value of R&D contracts awarded to the firm's SIC4 industry in year t) strengthens the validity of our instrument because it makes it less likely to be related to the focal firm's idiosyncratic technical opportunities.

D.2 Cold War Shock

Figure D1 presents the timeline used for estimating the *Cold War shock* instrumental variable.

Figure D1: The Cold War Identification Strategy Timeline



Notes: This figure presents the timeline used for estimating the second instrumental variable, *Cold War shock*.

D.3 First Stage Results

Table D6 shows the first stage results of the two-stage least squares (2SLS) instrumental variable estimations used in this paper.

Table D6: Instrumental Variable Estimation (First Stage)

	(1)	(2)	(3)	(4)
	ln(R&D contracts)$_{t-3}$			
	1st stage IV, Ind. R&D funding	1st stage IV, Cold War shock for R&D	1st stage IV, Cold War shock for pubs	1st stage IV, Cold War shock for pats
ln(Industry R&D funding)$_{t-3}$	0.072			
	(0.007)			
ln(Cold War shock)		0.033	0.029	0.037
		(0.008)	(0.007)	(0.008)
Pre-sample mean R&D expenditures		0.472		
		(0.058)		
Pre-sample mean publications			0.914	
			(0.072)	
Pre-sample mean patents				0.813
				(0.081)
ln(R&D stock)$_{t-3}$	0.040	0.111	0.125	0.195
	(0.030)	(0.042)	(0.027)	(0.029)
Sample years	1980-2015	1995-2015	1995-2015	1995-2015
Firm fixed effects	Yes	No	No	No
Year fixed effects	Yes	Yes	Yes	Yes
Observations	41,047	5,514	5,861	5,861
F statistic	50	103	119	113
Adjusted R-squared	0.704	0.089	0.117	0.102

Notes: This table displays first stage OLS regression results. *Industry R&D funding* is calculated by multiplying the level of R&D contracts obligated to the focal firm's SIC3 industry (not including the contracts obligated to the focal firm that year) times the share of R&D contracts obligated to the focal firm's SIC4 industry (averaged over the sample period of 1980-2015). The *Cold War shock* is calculated using the difference in average contract values between pre- (1986-1988) and post- (1990-1992) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries during 1982-1985. The pre-sample means are calculated using data from 1980-1988. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level in Column 1, and are robust to arbitrary heteroskedasticity in Columns 2-4.

Appendix E Agency Variation

Federal agencies are heterogeneous in their mission orientation.[81] We classify four agencies as mission-driven, including DoD, NASA, HHS, and DoT. As shown in Appendix Table B1, these agencies are in the top 10 by total procurement value during 1980-2015, and they award an above-average share of dollars for R&D services.

Federal agencies are also heterogeneous in the size and composition of their procurement contracts, as can be seen in Appendix Table E7, as well as the characteristics of their contractors, as can be seen in Appending Table E8.

[81] For example, DoD is focused on its mission "to provide the military forces needed to deter war and ensure our nation's security." Conversely, GSA "deliver(s) value and savings in real estate, acquisition, technology, and other mission-support services across government." Mowery (2009b) categorizes federal R&D investments in defense, space exploration, energy, agriculture, industrial technology development, and health as mission-driven. Similarly, Goldfarb (2008) categorizes DoD, NASA, HHS, DoC, DoE, and USDA as mission agencies.

Table E7: Contract Descriptive Statistics by Awarding Agency

	(1)	(2)	(3)	(4)	(5)	(6)
				Distribution		
	No. of contracts	Mean	Std. dev.	10th	50th	90th
DoD						
All contracts ($ mm)	4,407,829	1.1	56.2	0.0	0.0	0.5
R&D contracts ($ mm)	153,965	4.9	134.9	0.1	0.3	4.2
Product contracts ($ mm)	3,512,285	0.9	53.8	0.0	0.0	0.3
Noncompetitive product contracts ($ mm)	1,068,261	2.0	84.1	0.0	0.1	0.7
NASA						
All contracts ($ mm)	75,925	4.3	206.5	0.0	0.1	1.2
R&D contracts ($ mm)	19,394	7.3	191.7	0.0	0.3	4.0
Product contracts ($ mm)	31,940	2.1	83.1	0.0	0.1	0.4
Noncompetitive product contracts ($ mm)	8,158	4.8	128.8	0.0	0.0	0.4
DoT						
All contracts ($ mm)	24,904	1.7	26.9	0.0	0.1	1.2
R&D contracts ($ mm)	2,034	3.8	61.9	0.0	0.2	1.6
Product contracts ($ mm)	10,450	1.2	26.9	0.0	0.1	0.7
Noncompetitive product contracts ($ mm)	3,360	0.7	6.5	0.0	0.1	0.5
HHS						
All contracts ($ mm)	111,320	0.8	22.1	0.0	0.0	0.2
R&D contracts ($ mm)	2,990	2.3	12.6	0.0	0.1	2.7
Product contracts ($ mm)	69,498	0.7	23.2	0.0	0.0	0.1
Noncompetitive product contracts ($ mm)	19,779	0.3	10.2	0.0	0.0	0.1
DoE						
All contracts ($ mm)	16,984	18.8	882.2	0.0	0.0	1.3
R&D contracts ($ mm)	1,928	3.0	15.5	0.0	0.4	4.0
Product contracts ($ mm)	8,016	2.9	52.4	0.0	0.0	0.3
Noncompetitive product contracts ($ mm)	1,720	12.0	111.6	0.0	0.0	0.4
DHS						
All contracts ($ mm)	55,254	1.0	22.7	0.0	0.0	0.5
R&D contracts ($ mm)	828	3.2	30.4	0.0	0.1	3.0
Product contracts ($ mm)	32,389	0.5	25.5	0.0	0.0	0.3
Noncompetitive product contracts ($ mm)	10,696	0.8	35.9	0.0	0.0	0.3
DoC						
All contracts ($ mm)	39,830	0.4	9.3	0.0	0.0	0.3
R&D contracts ($ mm)	375	3.5	50.4	0.0	0.1	1.4
Product contracts ($ mm)	24,413	0.2	3.3	0.0	0.0	0.3
Noncompetitive product contracts ($ mm)	5,408	0.1	0.8	0.0	0.0	0.2
Other						
All contracts ($ mm)	4,200,193	0.3	62.9	0.0	0.0	0.1
R&D contracts ($ mm)	35,043	4.9	143.7	0.0	0.2	2.9
Product contracts ($ mm)	3,497,760	0.1	9.9	0.0	0.0	0.1
Noncompetitive product contracts ($ mm)	746,420	0.1	16.2	0.0	0.0	0.0

Notes: This table displays contract-level descriptive statistics over the sample period of 1980-2015 by awarding agency. The unit of analysis is a contract. The 4-digit *Product or service code* (PSC) associated with each contract was used to identify different types of contracts. *R&D contracts* have PSC codes that start with the letter "A." *Product contracts* have PSC codes that start with digits "1" through "9." *Noncompetitive product contracts* are exempted from full and open competition (e.g., due to a unique engineering, developmental, or research capability; due to national interest; as required by statute, etc.).

Table E8: R&D Contractor Descriptive Statistics by Awarding Agency

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
	DoD		NASA		DoT		HHS		DoE		DHS		DoC		Other	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
R&D expenditures ($ mm)	275	937	424	1,230	820	1,719	453	1,158	651	1,571	746	1,624	643	1,244	451	1,255
Publications	32	137	53	175	84	236	79	236	73	184	82	242	104	275	54	183
Patents	63	250	104	362	182	513	100	376	120	247	188	532	193	553	98	320
All contracts ($ mm)	288	2,080	739	3,389	1,521	4,874	810	3,737	1,513	4,948	1,522	5,017	1,801	5,552	510	2,795
R&D contracts ($ mm)	48	448	131	737	271	1,069	138	804	280	1,090	254	1,088	316	1,202	85	603
Non-R&D contracts ($ mm)	240	1,689	609	2,745	1,251	3,942	673	3,029	1,232	3,994	1,268	4,061	1,485	4,504	425	2,268
Commercial contracts ($ mm)	28	163	57	204	118	288	70	274	114	304	130	355	126	314	53	225
Noncommercial contracts ($ mm)	241	1,856	654	3,103	1,380	4,470	679	3,245	1,500	4,764	1,315	4,391	1,561	4,983	430	2,498
All grants ($ mm)	1	12	2	10	4	14	2	8	6	32	3	13	4	13	2	15
Sales ($ mm)	5,757	18,188	9,287	25,760	17,775	36,061	8,962	21,523	16,516	34,578	18,649	37,217	13,362	24,683	10,874	30,100
R&D stock ($ mm)	1,166	4,362	1,948	6,172	3,540	8,491	1,931	5,420	2,975	7,969	3,198	7,870	2,854	6,022	1,900	5,903

Notes: This table displays contractor descriptive statistics over the sample period of 1980-2015 by awarding agency. The unit of analysis is a firm-year. Statistics are only provided for R&D contractors. Grants and commercial contracts are only summarized for years 2001-2015 and 1994-2015, respectively.

Appendix F Industry Variation

Table F9 presents descriptive statistics by main industry, while Figure H3 shows changes in the share of all contracts (by value) awarded for R&D contracts and commercial contracts, respectively, by main industry.

Table F9: Descriptive Statistics by Main Industry

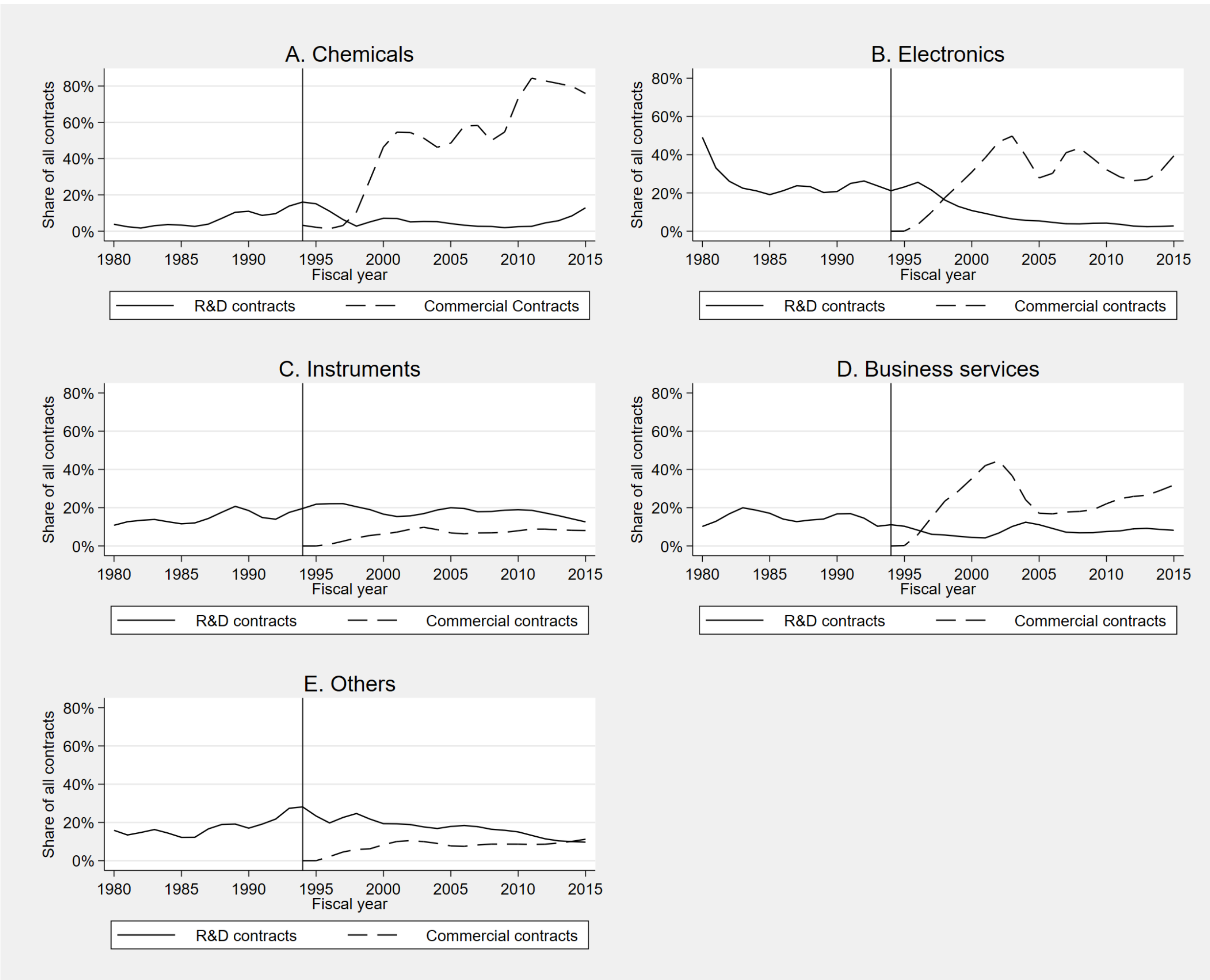
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Chemicals		Electronics		Instruments		Business services		Others	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
R&D expenditures ($ mm)	269	912	120	496	47	140	203	899	167	757
Publications	55	172	9	44	7	26	22	169	15	85
Patents	31	84	35	148	13	47	43	344	30	116
All contracts ($ mm)	14	111	22	202	126	1,135	31	209	273	2,205
R&D contracts ($ mm)	1	7	4	72	22	239	3	25	45	473
Non-R&D contracts ($ mm)	13	109	19	154	104	917	28	190	228	1,792
Commercial contracts ($ mm)	9	96	5	59	11	81	7	49	26	164
Noncommercial contracts ($ mm)	5	47	12	118	115	1,013	20	145	247	2,046
All grants ($ mm)	1	16	0	4	0	2	0	1	1	18
Sales ($ mm)	3,313	8,829	1,805	7,066	813	2,747	1,966	9,862	8,044	25,606
R&D stock ($ mm)	1,110	4,122	497	2,194	191	550	753	3,878	626	3,467

Notes: This table displays descriptive statistics over the sample period of 1980-2015 by main industry. The unit of analysis is a firm-year. Statistics are only provided for contractors. Grants and commercial contracts are only summarized for years 2001-2015 and 1994-2015, respectively.

Table F10 breaks the main results by industry. Column 1 presents OLS results for *Publications*. The relationship of R&D contracts with publications is positive across all industries. Column 2 presents estimates from the second stage of 2SLS regressions using *Industry R&D funding* and its interactions with industry indicator variables as instrumental variables. The estimates suggest that the causal effect of *R&D contracts* on publications is present across all industries (p-value = 0.061).

Column 3 presents OLS results using *Patents* as the dependent variable. The coefficient estimates show that the correlation between R&D contracts and patents is positive for all industries. However, we do not find evidence in Column 4 that *R&D contracts* drive patents across a variety of industries.

Figure F2: Trends in the Composition of Contracts by Main Industry



Notes: This figure presents the trend in the share of R&D contracts in all the contracts obligated by federal agencies to sample firms by main industry (solid lines). It also presents the trend in the share of commercial contracts in all contracts (dashed lines). The vertical lines mark the passage of the Federal Acquisition Streamlining Act of 1994.

Table F10: Variation by Main Industry

	(1)	(2)	(3)	(4)
	ln(Publications)		ln(Patents)	
	OLS	2nd stage IV, Ind. R&D funding	OLS	2nd stage IV, Ind. R&D funding
ln(R&D contracts)$_{t-3}$	0.014	0.041	0.011	-0.006
	(0.003)	(0.025)	(0.004)	(0.042)
ln(R&D contracts)$_{t-3}\times$ [Chemicals = 1]	-0.008	0.053	-0.010	-0.080
	(0.005)	(0.045)	(0.005)	(0.056)
ln(R&D contracts)$_{t-3}\times$ [Instruments = 1]	-0.001	-0.036	-0.001	-0.001
	(0.005)	(0.042)	(0.006)	(0.052)
ln(R&D contracts)$_{t-3}\times$ [Business services = 1]	-0.004	-0.030	0.010	-0.091
	(0.008)	(0.040)	(0.012)	(0.073)
ln(R&D contracts)$_{t-3}\times$ [Others = 1]	-0.006	0.104	-0.001	-0.042
	(0.005)	(0.057)	(0.006)	(0.080)
ln(R&D stock)$_{t-3}$	0.131	0.112	0.252	0.242
	(0.011)	(0.011)	(0.015)	(0.015)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		3.29		3.29
Firms	3,632	3,580	3,632	3,580
Observations	43,914	41,047	43,914	41,047
Adjusted R-squared	0.873	-0.111	0.847	0.027

Notes: This table presents the estimation results for the relationship of R&D contracts with publications and patents by main industry. The excluded industry indicator variable is *Electronics*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

Appendix G Robustness Checks and Alternative Explanations

G.1 Excluding Agencies

One concern may be that our results could be driven by a single agency. For example, the Department of Defense—which awards more procurement contracts than all other agencies combined—may have specific secrecy requirements that could affect patenting behavior, as well as undermine our identification strategy that treats the end of the Cold War as an exogenous shock to our sample firms. As shown in Tables G11, G12, and G13, our results are not driven solely by DoD R&D contracts. The coefficient estimates on *Non-DoD R&D contracts* are significantly larger in both the R&D expenditures equation and the publication equation.[82] Our results are also robust to excluding each of the other main agencies.

Table G11: R&D Expenditures Equation Excluding Agencies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	ln(R&D expenditures)								
	Top 7 Agencies	Other Agencies	Excluding DoD	Excluding NASA	Excluding DoT	Excluding HHS	Excluding DoE	Excluding DHS	Excluding DoC
ln(Top 7 R&D contracts)$_{t-3}$	0.073 (0.027)								
ln(Other R&D contracts)$_{t-3}$		0.491 (0.203)							
ln(Non-DoD R&D contracts)$_{t-3}$			0.211 (0.086)						
ln(Non-NASA R&D contracts)$_{t-3}$				0.070 (0.026)					
ln(Non-DoT R&D contracts)$_{t-3}$					0.070 (0.026)				
ln(Non-HHS R&D contracts)$_{t-3}$						0.075 (0.027)			
ln(Non-DoE R&D contracts)$_{t-3}$							0.072 (0.026)		
ln(Non-DHS R&D contracts)$_{t-3}$								0.070 (0.026)	
ln(Non-DoC R&D contracts)$_{t-3}$									0.070 (0.026)
ln(R&D stock)$_{t-3}$	0.327 (0.017)	0.352 (0.023)	0.333 (0.019)	0.327 (0.018)	0.327 (0.018)	0.328 (0.018)	0.328 (0.018)	0.327 (0.018)	0.327 (0.018)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)	90.86	26.60	34.96	97.38	96.88	88.68	94.70	94.89	95.82
Firms	3,414	3,417	3,416	3,414	3,414	3,414	3,414	3,414	3,414
Observations	37,056	37,221	37,113	37,080	37,052	37,065	37,066	37,054	37,052
Adjusted R-squared	0.046	-0.586	-0.167	0.049	0.048	0.045	0.046	0.048	0.048

Notes: This table presents the robustness of estimation results for the effect of R&D contracts on R&D expenditures to excluding contracts from certain agencies. Columns 1-9 present the second stage of 2SLS, where R&D contracts are instrumented using *Industry R&D funding*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

[82] Evaluated at the sample means, the coefficient estimate in Column 3 of Table G12 indicates that a $1.2 million increase in *Non-DoD R&D contracts* leads to one additional publication.

Table G12: PUBLICATION EQUATION EXCLUDING AGENCIES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	ln(Publications)								
	Top 7 Agencies	Other Agencies	Excluding DoD	Excluding NASA	Excluding DoT	Excluding HHS	Excluding DoE	Excluding DHS	Excluding DoC
ln(Top 7 R&D contracts)$_{t-3}$	0.036 (0.019)								
ln(Other R&D contracts)$_{t-3}$		0.283 (0.137)							
ln(Non-DoD R&D contracts)$_{t-3}$			0.118 (0.059)						
ln(Non-NASA R&D contracts)$_{t-3}$				0.035 (0.018)					
ln(Non-DoT R&D contracts)$_{t-3}$					0.035 (0.018)				
ln(Non-HHS R&D contracts)$_{t-3}$						0.038 (0.019)			
ln(Non-DoE R&D contracts)$_{t-3}$							0.035 (0.018)		
ln(Non-DHS R&D contracts)$_{t-3}$								0.034 (0.018)	
ln(Non-DoC R&D contracts)$_{t-3}$									0.034 (0.018)
ln(R&D stock)$_{t-3}$	0.114 (0.010)	0.126 (0.013)	0.119 (0.011)	0.114 (0.010)	0.114 (0.010)	0.114 (0.011)	0.114 (0.010)	0.114 (0.010)	0.114 (0.010)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)	92.48	29.84	39.01	102.11	100.62	92.33	98.71	98.79	99.76
Firms	3,580	3,584	3,584	3,580	3,580	3,580	3,580	3,580	3,580
Observations	41,053	41,221	41,110	41,076	41,046	41,061	41,060	41,049	41,047
Adjusted R-squared	0.016	-0.382	-0.101	0.015	0.015	0.013	0.016	0.016	0.016

Notes: This table presents the robustness of estimation results for the effect of R&D contracts on publications to excluding contracts from certain agencies. Columns 1-9 present the second stage of 2SLS, where R&D contracts are instrumented using *Industry R&D funding*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

G.2 Other Funding Shocks

Another way we mitigate the concern that the Cold War shock could suffer from endogeneity—if strategic defense investments such as the Star Wars program led to the collapse of the Soviet Union—is by examining two alternative shocks. First, we use changes in procurement that were triggered by the terrorist attacks on September 11, 2001. Government procurement contracts were reallocated to support Operation Iraqi Freedom, Operation Enduring Freedom, and other military campaigns that were part of the new Global War on Terrorism, as shown in Table H28. Second, we use changes in procurement that resulted from federal efforts to manage the financial crisis during the Great Recession of 2007-2008. Government procurement contracts were reallocated to support the hard-hit auto and aircraft industries, as shown in Table H29. Table G14 shows that the effect of *R&D contracts* on publications is robust to instrumenting for the endogenous R&D contracts using either the *Global War on Terrorism shock* or the *Financial Crisis shock*.[83]

[83]Table G14 uses the pre-sample mean publications calculated for the original Cold War shock (i.e., during 1980-1988), but our results hold for alternative pre-sample periods, such as 1980-1990 or 1980-1995.

Table G13: Patent Equation Excluding Agencies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					ln(Patents)				
	Top 7 Agencies	Other Agencies	Excluding DoD	Excluding NASA	Excluding DoT	Excluding HHS	Excluding DoE	Excluding DHS	Excluding DoC
ln(Top 7 R&D contracts)$_{t-3}$	-0.043 (0.025)								
ln(Other R&D contracts)$_{t-3}$		-0.289 (0.175)							
ln(Non-DoD R&D contracts)$_{t-3}$			-0.126 (0.078)						
ln(Non-NASA R&D contracts)$_{t-3}$				-0.043 (0.024)					
ln(Non-DoT R&D contracts)$_{t-3}$					-0.040 (0.023)				
ln(Non-HHS R&D contracts)$_{t-3}$						-0.043 (0.024)			
ln(Non-DoE R&D contracts)$_{t-3}$							-0.041 (0.024)		
ln(Non-DHS R&D contracts)$_{t-3}$								-0.041 (0.023)	
ln(Non-DoC R&D contracts)$_{t-3}$									-0.040 (0.023)
ln(R&D stock)$_{t-3}$	0.242 (0.015)	0.230 (0.017)	0.237 (0.016)	0.241 (0.015)	0.241 (0.015)	0.241 (0.015)	0.241 (0.015)	0.241 (0.015)	0.241 (0.015)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)	92.48	29.84	39.01	102.11	100.62	92.33	98.71	98.79	99.76
Firms	3,580	3,584	3,584	3,580	3,580	3,580	3,580	3,580	3,580
Observations	41,053	41,221	41,110	41,076	41,046	41,061	41,060	41,049	41,047
Adjusted R-squared	0.045	-0.232	-0.050	0.042	0.045	0.043	0.044	0.045	0.045

Notes: This table presents the robustness of estimation results for the effect of R&D contracts on patents to excluding contracts from certain agencies. Columns 1-9 present the second stage of 2SLS, where R&D contracts are instrumented using *Industry R&D funding*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

G.3 Alternative Specifications

One concern may be that our choice of regression model (OLS) and data transformation (taking the natural logarithm of publications or patents plus one) could be inappropriate, given that *Publications* and *Patents* are over-dispersed count variables. Columns 1 and 4 in Table G15 present estimations using Poisson pseudo-maximum likelihood regressions. Consistent with our OLS results, we find that *R&D contracts* have positive relationships with publications and patents (p-value < 0.01 and p-value < 0.001, respectively). We also present OLS and 2SLS estimations where we use an inverse hyperbolic sine transformation.[84] Consistent with previous results, Columns 3 and 6 in Table G15 show that R&D contracts have a positive effect on publications (p-value < 0.05) , but not on patents. Moreover, the coefficient estimate on *R&D contracts* for the publication equation is close in size to our main specification in Table 4.

[84] The inverse hyperbolic sine is calculated as $asinh(x) = ln(x + \sqrt{x^2 + 1})$.

Table G14: Alternative Procurement Shocks

	(1) ln(R&D expenditures)	(2) ln(Publications)	(3) ln(R&D expenditures)	(4) ln(Publications)
	1st stage IV, Global War on Terrorism shock	2nd stage IV, Global War on Terrorism shock	1st stage IV, Financial Crisis shock	2nd stage IV, Financial Crisis shock
ln(R&D contracts)$_{t-3}$		0.372		0.077
		(0.092)		(0.037)
ln(Global War on Terrorism shock)	0.051			
	(0.012)			
ln(Financial Crisis shock)			0.091	
			(0.016)	
Pre-sample mean publications	2.022	0.188	2.039	0.735
	(0.096)	(0.188)	(0.124)	(0.081)
Sample years	2007-2015	2007-2015	2011-2015	2011-2015
Firm fixed effects	No	No	No	No
Year fixed effects	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		17.18		34.20
Observations	2,746	2,746	1,427	1,427
Adjusted R-squared	0.244	-0.445	0.257	0.576

Notes: This table presents the robustness of estimation results for the effect of R&D contracts on publications to using alternative procurement shocks. The *Global War on Terrorism shock* is calculated using the difference in total contract values between pre- (2000) and post- (2004) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries during 1994-1997. The *Financial Crisis shock* is calculated using the difference in total contract values between pre- (2007) and post- (2008) periods for each SIC4 industry, weighted by the focal firm's sales exposure to different SIC4 industries during 2000-2003. The pre-sample mean publications are calculated using data from 1980-1988. One is added to logged variables. Standard errors (in parentheses) are robust to arbitrary heteroskedasticity.

Table G15: Alternative Specifications

	(1) Publications	(2) Inv. hyperbolic sine(Publications)	(3)	(4) Patents	(5) Inv. hyperbolic sine(Patents)	(6)
	Poisson	OLS	2nd stage IV, Ind. R&D funding	Poisson	OLS	2nd stage IV, Ind. R&D funding
ln(R&D contracts)$_{t-3}$	0.008	0.014	0.043	0.014	0.013	-0.036
	(0.003)	(0.002)	(0.021)	(0.004)	(0.002)	(0.027)
ln(R&D stock)$_{t-3}$	0.464	0.175	0.151	0.395	0.323	0.306
	(0.052)	(0.016)	(0.015)	(0.061)	(0.020)	(0.021)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)			103.68			103.68
Firms	2,462	3,784	3,731	3,282	3,784	3,731
Observations	34,636	46,788	43,913	43,122	46,788	43,913
Adjusted R-squared		0.859	0.015		0.835	0.050

Notes: This table presents the robustness of estimation results for the relationship between R&D contracts and publications and patents to using Poisson pseudo-maximum likelihood regression (Columns 1 and 4) or transforming publications and patents using an inverse hyperbolic sine (Columns 2-3 and 5-6). One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

G.4 Time Lags

Our results are not sensitive to the specific lag structure assumed in our main specifications. Checking the sensitivity of our of results to lag structure is important because we do not observe the actual annual spending associated with contract awards. To construct our panel, we aggregate contract *obligations*, not actual *outlays*, at the firm-year level. Since multi-year contracts are common, the outlays may occur one, two, or more years after the original obligation date. Moreover, there is typically a lag between the year when the R&D activity is conducted and the year when the paper is published or the patent is granted. Therefore, the specific lag structure between receiving an award and publishing a scholarly paper or receiving a patent grant is unclear. However, our results are robust to alternative time lags. Table G16 indicates that R&D contracts have a positive effect on publications when using four- or five-year lags (p-value < 0.05). The coefficient estimates increase slightly compared to our main specification in Table 4. In unreported specifications, we find no effect of R&D contracts on patents when using four- or five-year lags.

Table G16: Publication Equation Using Alternative Time Lags

	(1)	(2)	(3)	(4)	(5)
	ln(Publications)				
	Finite distributed lags	One-year lags 2nd stage IV, Ind. R&D funding	Two-year lags 2nd stage IV, Ind. R&D funding	Four-year lags 2nd stage IV, Ind. R&D funding	Five-year lags 2nd stage IV, Ind. R&D funding
ln(R&D contracts)$_{t-1}$	0.005	0.006			
	(0.002)	(0.016)			
ln(R&D contracts)$_{t-2}$	0.003		0.021		
	(0.001)		(0.017)		
ln(R&D contracts)$_{t-3}$	0.004				
	(0.001)				
ln(R&D contracts)$_{t-4}$	0.004			0.039	
	(0.001)			(0.018)	
ln(R&D contracts)$_{t-5}$	0.004				0.043
	(0.001)				(0.018)
ln(R&D stock)$_{t-1}$	0.188	0.150			
	(0.015)	(0.010)			
ln(R&D stock)$_{t-2}$			0.135		
			(0.010)		
ln(R&D stock)$_{t-4}$				0.102	
				(0.011)	
ln(R&D stock)$_{t-5}$					0.087
					(0.011)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		110.83	106.94	94.78	90.42
Firms	3,096	4,315	3,918	3,279	3,000
Observations	36,506	49,639	45,118	37,345	33,961
Adjusted R-squared	0.884	0.048	0.036	0.007	-0.003

Notes: This table presents the robustness of estimation results for the relationship between R&D contracts and publications to using alternative time lags. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

G.5 Firm Subsamples

A concern is that our results could be driven by outliers. In unreported specifications, we find that our results in Tables 3, 4, and 5 are robust to using different firm subsamples. When we winsorize the 99th percentile of annual R&D contracts, we obtain almost identical 2SLS coefficient estimates on *R&D contracts* in the R&D expenditures, publication, and patent equations. When we use only publishing firms, the 2SLS coefficient estimate on *R&D contracts* in the publication equation is 0.041 (using the *Industry R&D funding* instrument) and 0.362 (using the *Cold War shock* instrument), respectively. When we use only contractor firms, the 2SLS coefficient estimate on *R&D contracts* is 0.031 and 0.596, respectively. These results indicate that the effect of R&D contracts on upstream corporate R&D can be generalized to our complete sample.

G.6 Related and Unrelated Publications

A concern may be that R&D contracts could crowd out unrelated research areas. For example, firms may respond to government R&D competitions by reducing their R&D activities in research areas that do not benefit directly from government spending. To test this possibility, we split the flow of corporate publications into related publications (i.e., those that acknowledge external support) and unrelated publications (i.e., those that do not). Similarly, we split the flow of corporate patents into those that self-cite at least one of the focal firms' related publications, and those that do not. As shown in Table G17, we do not find evidence to suggest that R&D contracts crowd out unrelated research areas (although we cannot rule it out due to imprecise estimation results).

Table G17: UNRELATED RESEARCH AREAS

	(1) ln(Related publications)	(2)	(3) ln(Unrelated publications)	(4)	(5) ln(Related patents)	(6)	(7) ln(Unrelated patents)	(8)
	OLS	2nd stage IV, Ind. R&D funding	OLS	2nd stage IV, Ind. R&D funding	OLS	2nd stage IV, Ind. R&D funding	OLS	2nd stage IV, Ind. R&D funding
ln(R&D contracts)$_{t-3}$	0.008	0.029	0.010	0.025	-0.000	0.002	0.011	-0.049
	(0.003)	(0.015)	(0.002)	(0.019)	(0.001)	(0.003)	(0.002)	(0.024)
ln(R&D stock)$_{t-3}$	0.062	0.051	0.155	0.138	0.007	0.005	0.291	0.281
	(0.012)	(0.011)	(0.014)	(0.013)	(0.006)	(0.005)	(0.019)	(0.019)
Sample years	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weak identif. (Kleibergen-Paap)		89.09		89.09		89.09		89.10
Firms	2,688	2,642	2,688	2,642	2,688	2,642	2,688	2,642
Observations	35,056	32,295	35,056	32,295	35,056	32,295	35,042	32,281
Adjusted R-squared	0.603	-0.015	0.854	0.026	0.316	-0.002	0.845	0.045

Notes: This table presents the robustness of estimation results for the relationship of R&D contracts with publications and patents to considering related and unrelated research areas. *Related publications* acknowledge external support, while *Unrelated publications* do not. *Related patents* self-cite at least one of the focal firm's *Related publications*, while *Unrelated patents* do not. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

G.7 Trends by Industry and Firm Subsamples

Table G18 presents changes in the composition of government contracts by industry, and in the relationship between total contracts and firm scientific capabilities for different firm subsamples.

Table G18: CHANGES OVER TIME

	(1)	(2)	(3)	(4)
	Contract composition		Scientific capabilities	
	Share R&D/ All contracts	Share comm./ All contracts	Publishing firms	Contractor firms
Time trend	-0.015	0.227	0.447	0.507
	(0.009)	(0.021)	(0.142)	(0.154)
Time trend x [Chemicals = 1]	0.116	-0.017		
	(0.111)	(0.123)		
Time trend x [Instruments = 1]	0.009	0.065		
	(0.032)	(0.028)		
Time trend x [Business services = 1]	-0.024	0.003		
	(0.019)	(0.080)		
Time trend x [Others = 1]	0.009	-0.019		
	(0.008)	(0.038)		
ln(Publications stock)$_{t-1}$			0.589	0.718
			(0.124)	(0.143)
Time trend × ln(Publications stock)$_{t-1}$			-0.135	-0.163
			(0.037)	(0.038)
ln(R&D stock)$_{t-1}$	-0.004	-0.029	0.376	0.459
	(0.006)	(0.015)	(0.084)	(0.095)
Sample years	1980-2015	1995-2015	1980-2015	1980-2015
Firm fixed effects	Yes	Yes	Yes	Yes
Firms	2,191	1,755	3,164	2,589
Observations	23,641	15,927	43,158	38,632
Adjusted R-squared	0.011	0.003	0.730	0.629

Notes: This table presents OLS estimates for trends in procurement contract composition by industry, and the relationship between total contracts and firm scientific capabilities for different firm subsamples. *Time trend* is divided by 10. The excluded industry indicator variable is *Electronics*. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

G.8 Trends by Decade

Table G19 presents the changing composition of government contracts allowing for nonlinear time effects.

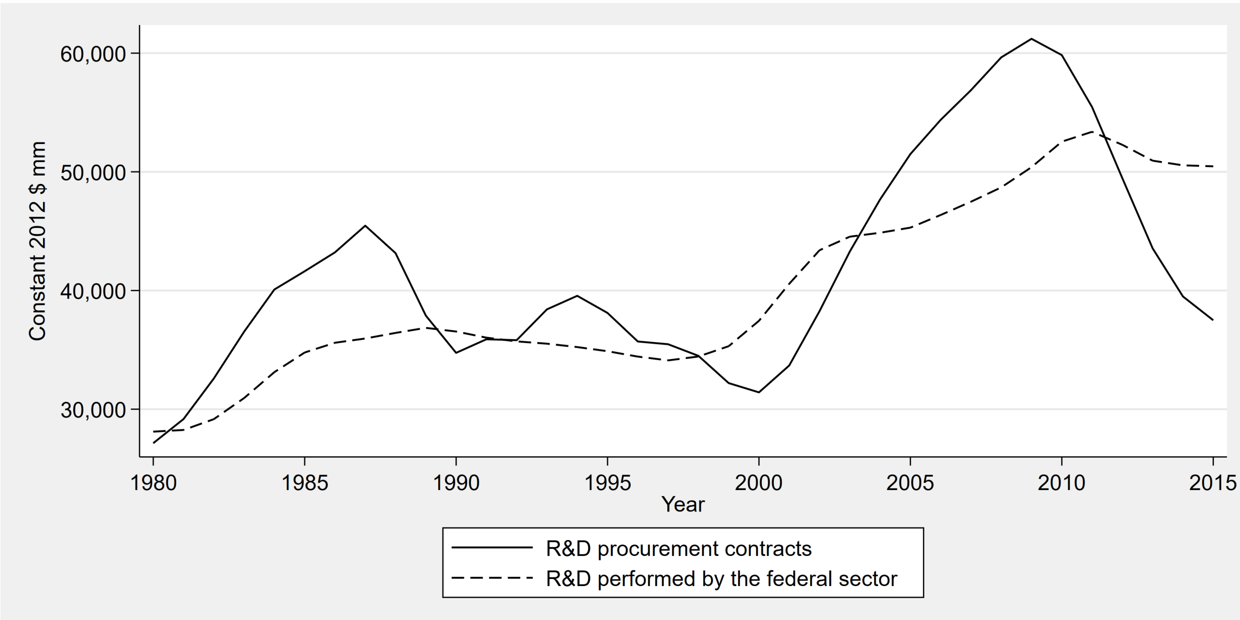
Table G19: Nonlinear Time Effects

	(1)	(2)	(3)	(4)	(5)
	Contract value			Contract composition	
	ln(All contracts)	ln(R&D contracts)	ln(Comm. contracts)	Share R&D/ All contracts	Share comm./ All contracts
Indicator for Decade = 1990s	-0.164	-0.207		0.029	
	(0.128)	(0.086)		(0.018)	
Indicator for Decade = 2000s	0.252	-0.191	2.266	0.008	0.204
	(0.178)	(0.127)	(0.103)	(0.021)	(0.021)
Indicator for Decade = 2010s	0.159	-0.523	2.927	0.013	0.435
	(0.216)	(0.148)	(0.143)	(0.049)	(0.037)
ln(R&D stock)$_{t-1}$	0.534	0.176	0.612	-0.003	-0.030
	(0.060)	(0.040)	(0.059)	(0.004)	(0.015)
Sample years	1980-2015	1980-2015	1995-2015	1980-2015	1995-2015
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Firms	4,516	4,519	3,782	2,191	1,755
Observations	55,941	56,030	38,692	23,641	15,927
Adjusted R-squared	0.735	0.651	0.684	0.010	0.006

Notes: This table presents OLS estimates for changes in procurement contract value and composition over time, accounting for nonlinear time effects. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

Appendix H Additional Figures and Tables

Figure H3: R&D Contracts vs. R&D Performed by the Federal Sector



Notes: This figure presents a comparison between R&D procurement contracts from all agencies (solid line) and R&D performed by the federal sector (dashed line) over time. Federal sector data are from Table 2 of the National Patterns of R&D Resources: 2017-2018 series published by the National Science Foundation at https://ncses.nsf.gov/pubs/nsf20307.

Table H20: Largest Contractors Over Time

Decade	Company	All contracts ($ mm)	R&D contracts ($ mm)	Sales ($ mm)	R&D expenditures ($ mm)	Publications (count)	Patents (count)
1980	Boeing	136,636	23,874	246,245	12,898	909	1,427
1980	General Dynamics	74,944	6,606	143,363	4,496	340	377
1980	United Technologies	70,000	6,123	294,253	16,555	1,240	2,604
1980	General Electric	67,366	10,760	633,418	19,427	6,020	9,114
1980	Raytheon	47,307	5,223	124,707	4,302	514	631
1980	Rockwell Automation	40,600	19,058	184,839	5,600	2,794	1,804
1980	McDonnell Douglas	37,152	5,452	197,205	7,601	1,062	306
1980	CBS	30,347	4,012	198,005	4,299	3,246	4,072
1980	Martin Marietta	28,137	10,868	80,362	2,441	738	131
1980	Litton Industries	22,085	1,495	89,381	1,931	863	511
1990	Lockheed Martin	148,397	35,029	271,608	10,494	3,984	1,416
1990	Boeing	122,863	40,361	470,980	21,286	1,851	1,776
1990	General Dynamics	82,426	14,550	76,350	1,466	219	237
1990	Northrop Grumman	62,877	11,240	98,814	2,298	750	882
1990	McDonnell Douglas	59,174	13,849	157,802	4,248	803	274
1990	Raytheon	52,289	12,067	173,796	4,939	1,247	1,127
1990	General Electric	40,907	9,360	1,036,285	19,978	4,440	8,910
1990	United Technologies	34,219	5,661	321,761	16,093	1,091	3,449
1990	CBS	32,396	3,121	125,330	1,484	1,078	2,316
1990	Rockwell Automation	26,292	9,228	146,157	7,983	1,876	1,710
2000	Lockheed Martin	355,328	92,584	400,471	11,186	2,871	3,012
2000	Boeing	305,601	54,682	667,733	32,370	2,387	3,838
2000	Northrop Grumman	177,992	39,014	289,648	5,413	1,373	2,287
2000	General Dynamics	167,739	25,413	233,535	3,807	567	322
2000	Raytheon	112,685	23,952	230,652	5,769	1,986	1,827
2000	United Technologies	89,146	15,767	463,339	16,029	1,033	3,276
2000	L3 Technologies	68,371	4,800	96,598	2,784	115	327
2000	General Electric	32,025	3,399	1,711,577	29,423	6,321	12,789
2000	McKesson	28,533	2	907,573	2,694	89	34
2000	Honeywell International	27,429	1,588	322,527	12,423	1,685	6,259
2010	Lockheed Martin	256,796	49,306	274,906	4,088	1,241	2,352
2010	Boeing	150,210	21,034	483,246	20,721	1,167	5,007
2010	General Dynamics	131,424	5,181	189,298	2,656	274	174
2010	Raytheon	84,775	13,891	143,825	3,606	1,084	2,205
2010	United Technologies	71,509	10,921	351,065	13,492	889	4,836
2010	Northrop Grumman	66,857	19,990	158,092	3,429	824	480
2010	L3 Technologies	52,272	3,075	79,029	1,834	93	282
2010	McKesson	32,877	1	854,633	2,553	812	153
2010	Huntington Ingalls Industries	25,543	345	33,547	103	7	4
2010	Honeywell International	18,659	452	223,770	10,579	872	6,607

Notes: This table displays the 10 largest contractors (by total value of contracts won) in each decade. Contracts, sales, R&D expenditures, publications, and patents are aggregated at the firm-decade level. The 2010s present aggregate data for just six years (2010-2015).

Table H21: CORRELATIONS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) DoD R&D contracts	1.00							
(2) NASA R&D contracts	0.27***	1.00						
(3) DoT R&D contracts	0.53***	0.20***	1.00					
(4) HHS R&D contracts	0.07***	0.01**	0.02***	1.00				
(5) DoE R&D contracts	0.30***	0.12***	0.13***	0.01**	1.00			
(6) DHS R&D contracts	0.15***	0.05***	0.02***	0.00	0.01	1.00		
(7) DoC R&D contracts	0.29***	0.12***	0.49***	0.01	0.11***	0.01*	1.00	
(8) Other R&D contracts	0.15***	0.11***	0.07***	0.02***	0.08***	0.01**	0.01***	1.00

Notes: This table displays pairwise Pearson correlations for R&D contracts received from various agencies. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Table H22: CORRELATIONS USING NORMALIZED R&D CONTRACTS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) DoD R&D contracts	1.00							
(2) NASA R&D contracts	0.08***	1.00						
(3) DoT R&D contracts	0.03***	0.05***	1.00					
(4) HHS R&D contracts	0.00	-0.00	-0.00	1.00				
(5) DoE R&D contracts	0.00	0.03***	0.00	-0.00	1.00			
(6) DHS R&D contracts	0.02***	-0.01	0.00	0.11***	-0.00	1.00		
(7) DoC R&D contracts	0.01*	0.19***	0.00	-0.00	0.00	-0.00	1.00	
(8) Other R&D contracts	0.05***	0.07***	0.04***	0.00	0.00	0.13***	0.01	1.00

Notes: This table displays pairwise correlations for R&D contracts received from various agencies. To avoid spurious correlations due to firm size, R&D contract values have been normalized by sales. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Table H23: R&D CONTRACTORS BY AWARDING AGENCY

Awarding agency	R&D contractors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) DoD	778	778 (100%)	217 (28%)	92 (12%)	108 (14%)	80 (10%)	79 (10%)	65 (8%)	247 (32%)
(2) NASA	249	217 (87%)	249 (100%)	64 (26%)	54 (22%)	59 (24%)	51 (20%)	44 (18%)	118 (47%)
(3) DoT	100	92 (92%)	64 (64%)	100 (100%)	35 (35%)	38 (38%)	38 (38%)	30 (30%)	67 (67%)
(4) HHS	204	108 (53%)	54 (26%)	35 (17%)	204 (100%)	31 (16%)	46 (23%)	33 (16%)	112 (55%)
(5) DoE	95	80 (84%)	59 (62%)	38 (40%)	31 (33%)	95 (100%)	25 (26%)	25 (26%)	67 (71%)
(6) DHS	91	79 (87%)	51 (56%)	38 (42%)	46 (51%)	25 (27%)	91 (100%)	25 (27%)	66 (73%)
(7) DoC	70	65 (93%)	44 (63%)	30 (43%)	33 (47%)	25 (36%)	25 (36%)	70 (100%)	54 (77%)
(8) Other	367	247 (67%)	118 (32%)	67 (18%)	112 (31%)	67 (18%)	66 (18%)	54 (15%)	367 (100%)

Notes: This table displays frequency counts and percentages of R&D contractors by awarding agency.

Table H24: Classification Into Main Industries

Main industry	SIC2 code	Description
Chemicals	28	Firms producing basic chemicals (including acids, alkalies, salts, and organic chemicals), chemical products used in manufacturing (including synthetic fibers, plastics materials, dry colors, and pigments), or finished chemical products used for ultimate consumption (including drugs, cosmetics, and soaps) or as supplies in other industries (including paints, fertilizers, and explosives).
Electronics	35, 36	Firms manufacturing industrial and commercial machinery, equipment, and computers (including engines and turbines; farm and garden machinery; construction, mining, and oil field machinery; elevators and conveying equipment; hoists, cranes, monorails, and industrial trucks and tractors; metalworking machinery; special industry machinery; general industrial machinery; computer and peripheral equipment and office machinery; and refrigeration and service industry machinery), or machinery, apparatus, and supplies for the generation, storage, transmission, transformation, and utilization of electrical energy (including electricity distribution equipment; electrical industrial apparatus; household appliances; electrical lighting and wiring equipment; radio and television receiving equipment; communications equipment; electronic components and accessories; and other electrical equipment and supplies).
Instruments	38	Firms manufacturing instruments (including professional and scientific) for measuring, testing, analyzing, and controlling, and their associated sensors and accessories; optical instruments and lenses; surveying and drafting instruments; hydrological, hydrographic, meteorological, and geophysical equipment; search, detection, navigation, and guidance systems and equipment; surgical, medical, and dental instruments, equipment, and supplies; ophthalmic goods; photographic equipment and supplies; or watches and clocks.
Business services	73, 87	Firms providing business services (including advertising, credit reporting, collection of claims, mailing, reproduction, stenographic, news syndicates, computer programming, photocopying, duplicating, data processing, services to buildings, and help supply services), or engineering, accounting, research, management, and related services (including engineering, architectural, and surveying services; accounting, auditing, and bookkeeping services; research, development, and testing services; and management and public relations services).

Notes: This table displays the classification scheme used to group sample firms into several main industries. Industries not specifically listed were classified as "Others."

Table H25: Distribution of Firms by SIC2 Industry

SIC2 code	Number of firms	SIC2 code	Number of firms	SIC2 code	Number of firms
28	796	32	29	14	5
36	680	49	27	21	5
38	672	22	26	60	4
73	567	27	23	63	4
35	540	51	21	10	3
37	145	29	21	75	3
34	101	59	15	12	3
30	79	01	14	76	3
87	70	65	13	61	3
48	67	79	13	42	2
20	64	23	10	45	2
39	60	24	9	54	2
99	59	17	8	72	2
33	58	16	8	47	2
26	50	78	8	07	2
67	46	31	7	64	2
13	46	62	6	44	1
50	34	82	6	02	1
25	31	15	6	70	1
80	30	58	5		

Notes: This table displays the distribution of sample firms by two-digit SIC code.

Table H26: R&D Contractors vs. Other Firms by Main Industry

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Chemicals		Electronics		Instruments		Business services		Others	
	Diff.	t	Diff.	t	Diff.	t	Diff.	t	Diff.	t
R&D expenditures ($ mm)	351.352	24.35	173.635	24.6	71.108	26.3	323.901	15.7	302.210	26.4
R&D intensity (in $ mm)	-20.850	-2.82	-0.358	-1.9	-0.012	-0.0	-3.063	-1.4	-0.452	-2.0
Publications per $1 mm in R&D exp.	0.189	1.69	0.348	5.1	-0.012	-0.1	0.091	0.4	0.112	2.6
Patents per $1 mm in R&D exp.	-0.079	-0.43	-1.088	-0.8	-0.489	-3.3	0.014	0.2	-1.008	-4.1
All grants ($ mm)	1.019	3.13	0.568	6.3	0.432	7.8	0.192	5.3	1.408	3.7

Notes: This table displays mean comparison tests between R&D contractors and other firms within the same main industry. *R&D intensity* is calculated as R&D expenditures divided by sales. Grants are only summarized for years 2001-2015. The two-sample t-tests use unequal variances.

Table H27: Procurement Contracts by SIC4 Industry around the End of the Cold War

Rank	SIC4	1988 Contracts ($ mm)	1992 Contracts ($ mm)	Industry description
1	7389	2,881	4,799	Business Services, Not Elsewhere Classified
2	7373	2,836	4,608	Computer Integrated Systems Design
3	9661	233	1,731	Space Research and Technology
4	2111	191	1,436	Cigarettes
5	4813	402	1,381	Telephone Communications, Except Radiotelephone
6	3523	1,157	2,100	Farm Machinery and Equipment
7	4812	2,055	2,985	Radiotelephone Communications
8	2833	1,096	1,774	Medicinal Chemicals and Botanical Products
9	0131	2	560	Cotton
10	5047	218	754	Medical, Dental, and Hospital Equipment and Supplies
...	...	...	...	...
765	3711	3,446	2,195	Motor Vehicles and Passenger Car Bodies
766	3669	5,079	3,668	Communications Equipment, Not Elsewhere Classified
767	3731	1,960	516	Ship Building and Repairing
768	1311	6,044	4,177	Crude Petroleum and Natural Gas
769	6794	2,063	185	Patent Owners and Lessors
770	3841	3,086	1,055	Surgical and Medical Instruments and Apparatus
771	3769	5,324	2,020	Guided Missile Space Vehicle Parts and Auxiliary Equipment, Not Elsewhere Classified
772	3442	5,028	1,671	Metal Doors, Sash, Frames, Molding, and Trim Manufacturing
773	3812	7,986	3,326	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical Systems and Instruments
774	3721	65,698	39,074	Aircraft

Notes: This table displays the total procurement contracts (in constant 2012 dollars) awarded by all federal agencies in 1988 and 1992 to each SIC4 industry. The observations are sorted in descending order of the difference between 1992 and 1988.

Table H28: Procurement Contracts by SIC4 Industry around the Beginning of the Global War on Terrorism

Rank	SIC4	2001 Contracts ($ mm)	2004 Contracts ($ mm)	Industry description
1	3721	43,620	58,724	Aircraft
2	4812	878	14,068	Radiotelephone Communications
3	7819	877	12,059	Services Allied to Motion Picture Production
4	7373	6,544	15,541	Computer Integrated Systems Design
5	1311	270	6,623	Crude Petroleum and Natural Gas
6	2833	144	6,177	Medicinal Chemicals and Botanical Products
7	3537	679	6,005	Industrial Trucks, Tractors, Trailers, and Stackers
8	2111	1,124	6,278	Cigarettes
9	4731	248	5,242	Arrangement of Transportation of Freight and Cargo
10	7389	7,494	11,771	Business Services, Not Elsewhere Classified
...	...	...	...	...
765	7371	4,554	1,001	Computer Programming Services
766	8221	3,808	0	Colleges, Universities, and Professional Schools
767	7379	6,091	722	Computer Related Services, Not Elsewhere Classified
768	3724	5,893	0	Aircraft Engines and Engine Parts
769	8741	6,756	0	Management Services
770	3728	9,663	0	Aircraft Parts and Auxiliary Equipment, Not Elsewhere Classified
771	3731	10,625	759	Ship Building and Repairing
772	1531	10,858	0	Operative Builders
773	8744	15,934	0	Facilities Support Management Services
774	8711	17,139	521	Engineering Services

Notes: This table displays the total procurement contracts (in constant 2012 dollars) awarded by all federal agencies in 2001 and 2004 to each SIC4 industry. The observations are sorted in descending order of the difference between 2004 and 2001.

Table H29: Procurement Contracts by SIC4 Industry around the Financial Crisis

Rank	SIC4	2007 Contracts ($ mm)	2008 Contracts ($ mm)	Industry description
1	3711	11,611	18,356	Motor Vehicles and Passenger Car Bodies
2	3721	68,801	74,202	Aircraft
3	3537	10,880	14,925	Industrial Trucks, Tractors, Trailers, and Stackers
4	2111	9,644	11,892	Cigarettes
5	1311	12,008	14,200	Crude Petroleum and Natural Gas
6	2013	256	2,389	Sausages and Other Prepared Meats Products
7	7819	11,936	14,041	Services Allied to Motion Picture Production
8	3442	7,792	9,627	Metal Doors, Sash, Frames, Molding, and Trim Manufacturing
9	2052	376	2,194	Cookies and Crackers
10	3829	75	1,528	Measuring and Controlling Devices, Not Elsewhere Classified
...	...	...	...	...
765	3561	962	604	Pumps and Pumping Equipment
766	4959	616	245	Sanitary Services, Not Elsewhere Classified
767	6099	4,143	3,742	Functions Related to Depository Banking, Not Elsewhere Classified
768	3341	748	296	Secondary Smelting and Refining of Nonferrous Metals
769	2812	1,913	1,368	Alkalies and Chlorine
770	2015	3,826	3,223	Poultry Slaughtering and Processing
771	6798	750	103	Real Estate Investment Trusts
772	3663	5,468	4,814	Radio and Television Broadcasting and Communications Equipment
773	9222	1,317	268	Legal Counsel and Prosecution
774	2833	9,732	8,317	Medicinal Chemicals and Botanical Products

Notes: This table displays the total procurement contracts (in constant 2012 dollars) awarded by all federal agencies in 2007 and 2008 to each SIC4 industry. The observations are sorted in descending order of the difference between 2008 and 2007.