# Guaranteed Public Demand and Corporate Scientific Research*

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**Abstract**

Using data on $5.9 trillion in U.S. government procurement contracts matched to firms, we show that firms invest in scientific research to increase their chances of landing downstream contracts. Identification is based on firm-specific exposure to changes in industry-level procurement and agency-level windfall funding resulting from congressional appropriations. We find that R&D contracts crowd-in R&D expenditures and drive scientific publications, but not patents. The effect is strong when downstream contracts are awarded without competition, for larger firms, and when market incentives are insufficient. However, the effect has weakened over time as the government increasingly decoupled R&D contracts from downstream procurement.

## 1 Introduction

The government affects corporate innovation by subsidizing R&D, directly through tax credits and grants, and indirectly through spillovers from government-funded R&D and support for education. A less studied channel is the ability of the government to increase the private value of products and services resulting from upstream and downstream R&D through government procurement (henceforth, "downstream procurement"). When market incentives are weak, firms can still invest in R&D if this investment increases their chances of landing

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lucrative downstream procurement with the government. In the present paper, we estimate the effect of government R&D contracts on corporate innovation and show that the effect operates through the mechanism of guaranteed demand: rewarding firms that demonstrate technological superiority in R&D races with downstream procurement. While this mechanism has been used by the government to de-risk upstream R&D, we show that it has weakened over the past three decades with the growing decoupling of R&D contracts from downstream procurement.

Understanding how government procurement drives corporate innovation is important due to its size, scope, and unique characteristics. Government procurement is large and growing. Between 1980 and 2015 (the last year of our sample), the U.S. government more than doubled its annual procurement, from $207 billion to $420 billion.[1] The 2015 amount includes $37.5 billion in R&D contracts, which is much larger than the $3.6 billion in federal grants awarded to businesses that year. Moreover, government procurement touches a broad set of firms and encompasses much more than just military acquisition, especially in recent decades. The share of nonmilitary procurement dollars in all government procurement has risen from 40% in 1982 to 68% in 2015. Yet, despite its size and scope, government procurement has been understudied in the voluminous innovation literature. Existing work has advanced our understanding of how grants affect scientific research and technology development by individuals and firms (e.g., Howell, 2017; Myers & Lanahan, 2022; Wallsten, 2000). However, by focusing on R&D subsidies, existing work has largely neglected the effect of demand-side policies on corporate R&D.[2]

R&D contracts are fundamentally different from grants in their objectives, requirements, and incentives. While grants are used to stimulate R&D activity that is in the public interest, R&D contracts are "used only when the principal purpose is the acquisition of

[1]All dollar amounts are reported in constant 2012 dollars.

[2]A handful of prior studies focus on procurement contracts (e.g., Lichtenberg, 1988; Moretti, Steinwender, & Van Reenen, 2021; Slavtchev & Wiederhold, 2016). However, none of them systematically match federal contracts to American firms at scale, distinguish between upstream and downstream corporate R&D, and explore the guaranteed demand mechanism behind the effect.

supplies or services."[3] Grants are a form of financial assistance. They typically have no precise timetables, only require best effort, and use advance payments. R&D contracts, on the other hand, are not "free money." They have schedules of milestones, require delivery of promised deliverables, and may use advance, progress, or performance-based payments.[4] A key distinction between R&D contracts and grants is *how* they encourage innovation. While both subsidize R&D (a supply-side effect), R&D contracts also carry the promise of future public demand (a demand-side effect). Because R&D contracts must be implemented in downstream procurement, the government faces the challenge of designing incentives that will not only encourage innovation, but also overcome inefficiencies in project implementation.[5] One way to overcome the implementation problem is to award the downstream procurement contract to the firm that successfully performs the R&D. Because downstream contracts are lucrative, firms should be willing to co-invest with the government to win the R&D race, leading to a crowding-in effect of R&D contracts on corporate innovation. This willingness to co-invest with the government should not be present for grants or tax subsidies. Because of these differences, R&D contracts and grants touch different types of firms, and in different ways.

The acquisition of the Human Landing System (HLS) that will take people back to the Moon provides an example of how the government procures new technologies. In April 2020, the National Aeronautics and Space Administration (NASA) awarded a combined $1 billion in R&D contracts to SpaceX, Blue Origin, and Dynetics to begin development of the HLS during a 10-month base period. In April 2021, under budgetary pressures, NASA awarded a single $2.9 billion R&D contract to SpaceX to continue development of the HLS. Blue Origin and Dynetics protested this award with the Government Accountability Office, but

[3] Federal Acquisition Regulation (FAR) Section 35.003.

[4] Grants and R&D contracts can also be compared in terms of intellectual property rights. While both grants and R&D contracts fall under the patent rights provisions of the Bayh-Dole Act of 1980 and its extensions, R&D contracts also fall under the data rights provisions prescribed in the Federal Acquisition Regulation (for civilian agencies) and the Defense Federal Acquisition Regulation (for DoD).

[5] Inefficiencies in project implementation may arise if there is a high degree of complementary between R&D and production, or if the government faces contractual problems due to the transfer of tacit knowledge and asymmetric information (Che, Iossa, & Rey, 2021).

lost. In July 2021, Blue Origin offered to cover up to $2 billion in contract costs for a chance to remain in the HLS competition.[6] Why would a for-profit company offer to spend $2 billion of their own money on government R&D? Because winning the R&D competition all-but-guarantees Blue Origin billions of dollars in downstream public demand for its lander technology.[7] This example shows that R&D contracts are not just about lowering the cost of R&D, but also about increasing the chances of landing downstream procurement contracts. As such, they tend to crowd-in company-funded R&D investments. That is, SpaceX, Blue Origin, and Dynetics choose to co-invest with the government in R&D anticipating that their investments would lead to future landing system purchases by the government.[8]

We estimate the effect of R&D contracts on corporate R&D expenditures, scientific publications authored by corporate scientists, and patents. We extend the panel of 4,520 firms and 60,885 firm-year observations from Arora, Belenzon, and Sheer (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 contracting activities using the value of R&D contracts and downstream procurement contracts awarded to the firms, upstream R&D using publications authored by corporate scientists, and downstream R&D using granted patents. With our newly assembled data we present three sets of results.

First, we document that federal procurement is no longer dominated by the acquisition of military products and services. Figure 1 shows that nonmilitary procurement represented 40% of all procurement dollars awarded in 1982, but 68% in 2015. A similar trend toward the demilitarization of R&D contracts can be seen in Figure E3. Correspondingly, we find that federal procurement touches a broad set of R&D-performing firms, not just military

[6] Blue Origin founder Jeff Bezos criticized NASA's decision to rely on a single company: "Instead of investing in two competing lunar landers as originally intended, the Agency chose to confer a multi-year, multi-billion-dollar head start to SpaceX. That decision broke the mold of NASA's successful commercial space programs by putting an end to meaningful competition for years to come." (Bezos, 2021).

[7] While NASA did not respond to Blue Origin's offer, in March 2022 the agency announced plans to develop a second Moon lander—where the solicitation would be open to all U.S. companies except SpaceX—that would meet the agency's future transportation needs.

[8] Mowery (2012) makes a similar argument that the procurement contract to supply semiconductor components for strategic missile guidance systems was the "prize" that incentivized Texas Instruments to develop the integrated circuit.

contractors.

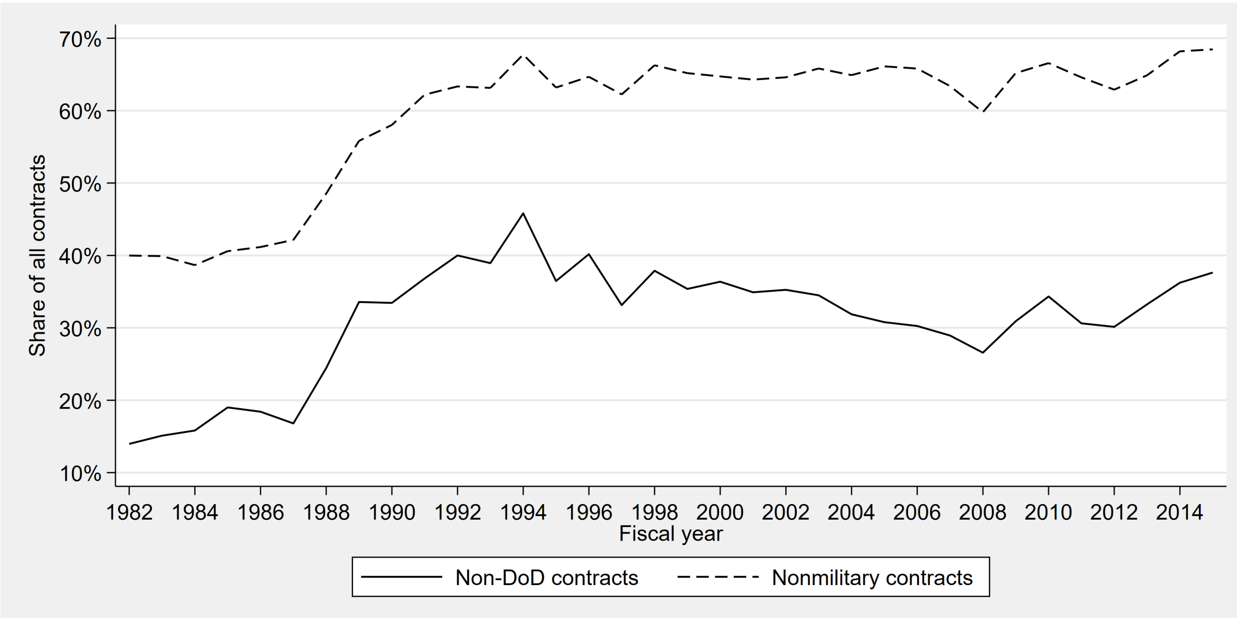


Figure 1: Share of Non-DoD and Nonmilitary Contracts in All Contracts Over Time
This figure plots the shares represented by non-DoD contract dollars (solid line) and nonmilitary contract dollars (dotted line), respectively, in all contract dollars obligated by federal agencies to all recipients (not limited to our sample firms) over time.

Second, R&D contracts crowd-in company-funded R&D expenditures and increase the number of scientific articles authored by corporate scientists, but not the number of patents. A key challenge in the analysis is how to deal with the endogeneity of contracts (David, Hall, & Toole, 2000). Common shocks can affect both government procurement and corporate R&D.[9] To mitigate this concern, we use variation in industry-level procurement and agency-level windfall funding resulting from the congressional appropriations process to predict firm-level R&D contracts. We also 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. The causal estimates point to a downward-bias in OLS estimates.

[9] If R&D contracts target firms that experience positive (negative) technology or demand shocks, then OLS estimates are upward-biased (downward-biased).

We explore the guaranteed demand mechanism—that R&D contracts crowd-in company-funded investment in upstream R&D because they carry the promise of future downstream procurement—behind the effect in several ways. First, we show that the effect of R&D contracts on publications is strong when downstream procurement is awarded without competition. Second, to the extent that transferring knowledge across firms is hard (Atalay, Hortaçsu, & Syverson, 2014), the effect should be strong for larger firms, which have the manufacturing capabilities and complementary assets necessary to execute downstream procurement contracts. Indeed, we find an effect of R&D contracts for the largest firms in our sample. Third, guaranteed public demand should drive corporate scientific research when capturing returns in (non-public) markets is difficult. Weak market incentives can arise when commercial applications for new technologies lie in the future (Weiss, 2014), knowledge spills over to rivals (Arora et al., 2021; Bloom, Schankerman, & Van Reenen, 2013), and incomplete contracts and asymmetric information make markets for technology inefficient (Arrow, 1962; Edler & Georghiou, 2007; Kremer, Levin, & Snyder, 2020). Consistent with this argument, we find an effect of R&D contracts on publications that are (i) not cited by the firm's own patents (consistent with limited downstream applications), (ii) cited by rival firms' patents (consistent with market-stealing due to spillovers to rivals), and (iii) not protected by the firm's own patents.

Our third set of results focus on how the effect of R&D contracts has changed over time. We show that the effect has weakened as policy reforms implemented in the 1980s and 1990s changed the composition of government procurement.[10] We document (i) the decreased importance of R&D races, (ii) the rise in competitive procurement, and (ii) the larger allocation of contracts to firms that do not participate in scientific research. These compositional changes suggest that the government has increasingly decoupled R&D races from downstream procurement.

[10]For example, the Federal Acquisition Streamlining Act of 1994 shifted procurement *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 that can be used in both military and commercial applications (Weiss, 2014).

The rest of the paper proceeds as follows: Section 2 positions our study in the literature and Section 3 provides the institutional context for government procurement. Section 4 presents the data, Section 5 outlines the econometric specifications, and Section 6 presents the estimation results. Section 7 discusses our contributions and concludes with directions for future work.

## 2 Related Literature

A voluminous literature examines the government's effect on corporate R&D through tax credits (e.g., Bloom, Griffith, & Van Reenen, 2002), grant funding (e.g., Azoulay, Graff Zivin, Li, & Sampat, 2019; Howell, 2017; Packalen & Bhattacharya, 2020; Wallsten, 2000), and spillovers from federal laboratories and universities (e.g., Adams, Chiang, & Jensen, 2003; Cohen, Nelson, & Walsh, 2002). Government procurement is also the subject of theoretical and empirical studies on optimal procurement mechanism design (e.g., Arve & Martimort, 2016; Bhattacharya, 2021; Che & Gale, 2003; Che et al., 2021; Decarolis, 2014; Riordan & Sappington, 1989), 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 (e.g., Lichtenberg, 1988; Moretti et al., 2021; Slavtchev & Wiederhold, 2016). To the best of our knowledge, none of them estimate the separate effect of R&D contracts on upstream and downstream corporate R&D or systematically test the guaranteed demand mechanism.

Most prior studies focus on funding from the Small Business Innovation Research (SBIR) program or the National Institutes of Health (NIH).[11] For example, small-firm research shows that SBIR awards crowd out company-funded R&D expenditures (Wallsten, 2000). Yet, early stage SBIR awards also increase forward citation-weighted patents, especially for financially

[11] The SBIR program is structured in three phases, but only Phase I and II are funded through SBIR grants or contracts, depending on the participating agency (see https://beta.www.sbir.gov/participating-agencies). Phase III focuses on commercialization and, in some agencies, may include non-SBIR funded R&D or downstream procurement contracts.

constrained small firms (Howell, 2017). In a recent paper, Howell, Rathje, Van Reenen, and Wong (2021) evaluate policy reforms aimed at changing how the U.S. Air Force SBIR program procures new technologies from small firms. 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 contract increases the likelihood of raising venture capital funding and improves the chances of winning a subsequent non-SBIR contract from the DoD. This finding supports the premise that winning R&D races is a pathway to subsequent downstream procurement.

Azoulay et al. (2019) show that National Institutes of Health (NIH) grants have a positive effect on corporate R&D. 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. Between the 1990s and the 2000s, grant support shifted from "edge science" toward more traditional science (Packalen & Bhattacharya, 2020). This coincides with the shift in procurement contracts from mission-focused technologies to commercial and dual-use items. It suggests that the government's withdrawal from funding risky, explorative science has occurred not only in contracts, but also in grants.

A few studies examine procurement contracts and are more closely related to our paper. Lichtenberg (1988) investigates the effect of procurement contracts on firm R&D expenditures using a panel of 169 U.S. contractors during 1979-1984. He estimates that a $1 increase in competitive procurement (including both R&D and non-R&D contracts) increases company-funded R&D expenditures by $0.54, and suggests the reason why is that winning contractors are almost guaranteed to receive much larger follow-on noncompetitive contracts. This supports the view that R&D contracts drive corporate innovation because they represent a "ticket to play" in the lucrative downstream public market.

Moretti et al. (2021) study the effect of government-funded R&D on private R&D investment and productivity growth using industry-level data from OECD countries and firm-level data from France during 1980-2015. They also find a crowding-in effect, whereby increases in government-funded R&D for an industry or firm drive additional private R&D investment in that industry or firm.

Slavtchev and Wiederhold (2016) study how the technological intensity of downstream procurement (not including R&D contracts) affects private R&D expenditures using a panel of U.S. states during 1999-2009. They estimate that each procurement dollar that the government shifts from low-tech industries to high-tech industries induces an additional $0.21 in private R&D expenditures. This crowding-in effect does not result from an increase in overall public demand, but rather from an increase in high-tech public demand. This suggests that the government can incentivize private R&D investment by changing the composition of its procurement.

Our work diverges from previous studies in several important ways. First, we examine the effect of R&D contracts separately on corporate research ("R") and development ("D").[12] This matters because the economic mechanism behind the effect—guaranteed demand—should be more relevant for upstream R&D than for downstream R&D.[13] Indeed, we find an effect of R&D contracts only on scientific research, especially when private market incentives are insufficient. Second, we make progress on data and identification. We match contracts from dozens of agencies to thousands of R&D-performing American firms and their subsidiaries

[12] A clear distinction between "R" and "D" is difficult to draw, both conceptually and empirically. Conceptually, while scientific knowledge is concerned with general laws and technical knowledge explains how and why specific artifacts work, both ultimately advance understanding. Empirically, while scientific research output tends to appear in publications and technology development output tends to appear in patents, the opposite can also happen.

[13] By its nature, upstream R&D is further from the market; therefore, private demand may be missing or lie further in the future. Upstream R&D may also be harder to protect. Government procurement can mitigate these two concerns (missing markets and appropriability) by creating exclusive public markets through guaranteed demand.

over several decades. We use aggregate industry-level contracts to predict firm-level contracts, similar to Moretti et al. (2021). But we also present causal evidence that exploits changes in procurement driven by geopolitical, rather than technological or demand, forces. Third, to our knowledge, we are first to analyze temporal changes in (i) the composition of government procurement and (ii) the relationship of contracts with firm scientific capabilities over several decades. These analyses are important for understanding the implications of procurement policies implemented throughout the 1980s and 1990s.

# 3 Background on Government Procurement

The U.S. government is the world's largest customer, procuring products and services worth 9.3% of the country's GDP in 2015.[14] The typical procurement process includes an agency identifying the products and services it needs, determining the best method for purchasing them, and carrying out the acquisition in accordance with the Federal Acquisition Regulation (FAR).[15] A more detailed discussion of the federal procurement process is included in Online Appendix A.

To understand the relevance of government procurement to corporate innovation, we must first understand which agencies buy, what they buy, from whom they buy, and how they use R&D contracts to buy new technologies. 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), NASA, General Services Administration (GSA), and Health and Human Services (HHS) together account for another 16% (see Table B1). Even within the DoD, there is significant heterogeneity in the size and composition of contracts by subagency. For example, the Air Force, Navy, and Army each awarded more than $2 trillion in contracts between 1980 and 2015. Of those dollars, 79-90% were awarded for downstream procurement. Conversely, the Defense Advanced Research Projects Agency

[14] Data are from Table 9.1 of OECD's *Government at a Glance 2017* report.

[15] "Agency" means either a federal department or an independent agency, commission, or other U.S. government entity.

(DARPA) awarded less than $14 billion in contracts, of which 91% were for R&D services. As a result, the military subagencies were in the position to guarantee demand, while DARPA was not.[16]

Despite the powerful position of the DoD, government procurement is no longer dominated by military products and services. The share of procurement dollars awarded by the DoD in all federal procurement dollars has declined from a high of 86% in 1982 to 62% in 2015. Moreover, the DoD itself is increasingly procuring dual-use and commercial products and services. The share of military procurement dollars in all DoD procurement dollars has declined from a high of 73% in 1980 to 51% in 2015. Combined, these trends have shifted federal procurement decidedly in favor of nonmilitary products and services, as shown in Figure 1.

Government procurement touches a broad range of industries and firms. Between 1980 and 2015, federal agencies awarded contracts to firms in 351 industries (identified by three-digit Standard Industrial Classification or SIC code), including 21 industries that received more than $100 billion each, 54 that received more than $10 billion, and 58 that received more than $1 billion. Over the same period, 10 industries received more than $1 billion in R&D contracts each. [17] These R&D-intensive industries received a combined $541 billion in R&D contracts and $2.8 trillion in downstream procurement contracts during 1980-2015.

In this paper, we focus on the effect of R&D contracts because awarding R&D contracts is how federal agencies manifest public demand for new technologies. Indeed, the FAR explicitly states that R&D contracts are used (i) to acquire products and services (ii) when the work or

[16]DARPA is the DoD's central R&D organization, established in 1958 "to make pivotal investments in breakthrough technologies for national security." Unlike other DoD subagencies, DARPA focuses on R&D projects that expand the frontiers of science and technology beyond immediate military requirements. It is independent of other military subagencies and reports directly to senior DoD management.

[17]While the Top 10 was dominated by Aircraft and Parts (SIC 372), it also included Space Research and Technology (SIC 966), Guided Missiles and Space Vehicles and Parts (SIC 376), Research, Development, and Testing Services (SIC Code 873), Engineering, Architectural, and Surveying (SIC 871), Miscellaneous Business Services (SIC 738), Search, Detection, Navigation, Guidance, Aeronautical, and Nautical Systems, Instruments, and Equipment (SIC 381), Miscellaneous Services (SIC 899), Computer Programming, Data Processing, and other Computer Related Services (SIC 737), and Management and Public Relations Services (SIC 874).

methods cannot be specified in advance.[18] As shown in Figure 2, R&D contracts represent a significant investment in innovation. While R&D contracts (solid line) are comparable in value to the R&D performed by the federal sector (dashed line), they are an order of magnitude larger than the federal grants awarded to businesses (dotted line).

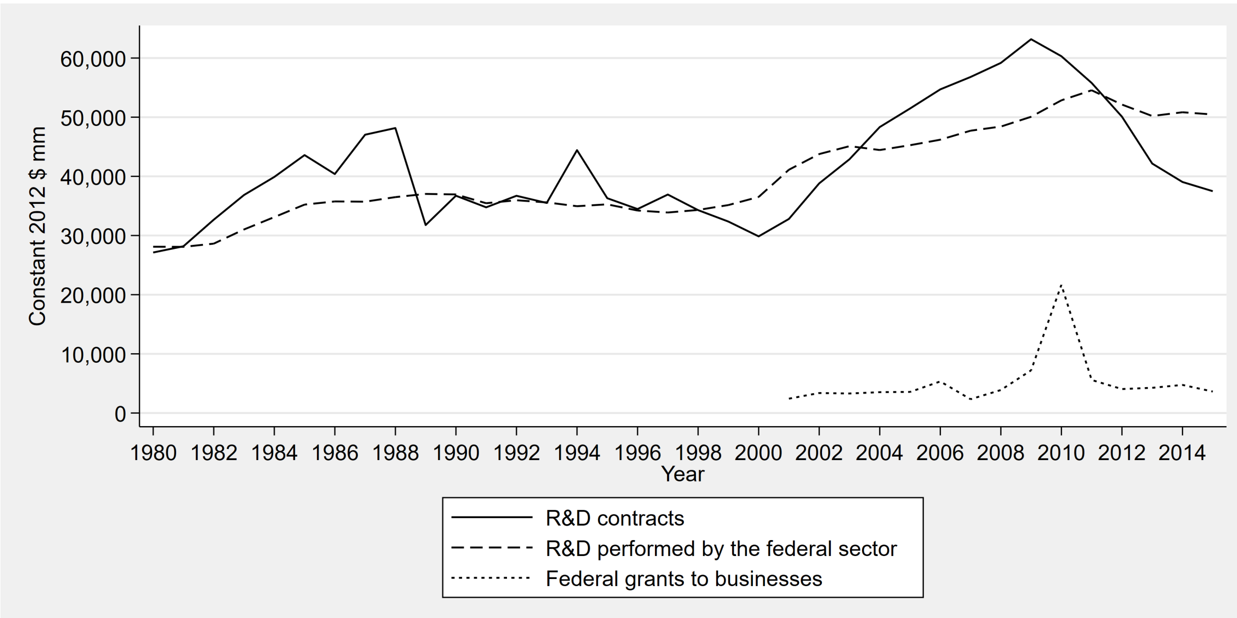


Figure 2: R&D Contracts, Grants to Businesses, and R&D Performed by the Federal Sector

This figure presents a comparison between R&D contracts (solid line), R&D performed by the federal sector (dashed line), and federal grants awarded to businesses (dotted line) over time. Federal sector data are from Table 2 of the National Patterns of R&D Resources: 2017-2018 series available at `https://ncses.nsf.gov/pubs/nsf20307`. Federal grants to businesses are presented from 2001, the first year of grant coverage in USAspending.gov.

# 4 Data

We combine data from three primary sources: (i) corporate R&D data, including matched patents and academic publications (Arora et al., 2021); (ii) government procurement data

[18] FAR Section 35.003 notes that R&D contracts "shall be used only when the principal purpose is the acquisition of supplies or services for the direct benefit or use of the Federal Government." FAR Section 35.002 adds that "Unlike contracts for supplies and services, most R&D contracts are directed toward objectives for which the work or methods cannot be precisely described in advance. It is difficult to judge the probabilities of success or required effort for technical approaches, some of which offer little or no early assurance of full success."

reported to the Federal Procurement Data System (FPDS); and (iii) government grant data reported to the Treasury DATA Act Broker. Our data construction work is detailed in Online Appendix B.

## 4.1 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 federal grants awarded during fiscal years 2001-2015.[19] 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 positive R&D expenditures during 1980-2015, (ii) at least one granted patent during 1980-2015, and (iii) at least three years of consecutive financial 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). We measure firms' upstream R&D using publications authored by corporate scientists, and downstream R&D using granted patents (similar to Arora, Belenzon, & Patacconi, 2018; Arora et al., 2021). Our variable construction work is detailed in Online Appendix C.

## 4.2 Government Contracts

We collect all federal procurement contracts and indefinite delivery vehicles (henceforth, "contracts") reported via two government websites, SAM.gov (for 1980-2000 data) and USAspending.gov (for 2001-2015 data).[20]

[19] We focus on "prime" contracts and grants awarded to firms that work directly with the government.

[20] An indefinite delivery vehicle (IDV) is a type of contract in which the government agrees to buy a product or service from a certain vendor for a certain quantity or time frame. The government does not

We match the names of contract recipient firms and their parent companies to the names of subsidiaries and their ultimate owners from our firm panel (see Online Appendix B for details). We identify 8.6 million unique contracts totalling \$5.9 trillion awarded by 72 federal agencies to 2,590 R&D-performing, publicly traded U.S. firms (henceforth, "contractors"). These matched contracts represent 47% of the value of all contracts awarded to all recipients (including small firms, private firms, foreign firms, etc.) during 1980-2015. Contractors typically receive multiple contracts per year. We aggregate the value of 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 (see Table B2 for the largest contractors by decade).

Agencies use a four-digit *Product or service code* to describe the principal product or service purchased in each contract.[21] We use this classification system to separate contracts into *R&D contracts* and *non-R&D contracts* (i.e., downstream procurement). 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) from the Defense Logistics Agency and Census Bureau to identify the primary four-digit industry (SIC4) 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 commercially available products and services to the maximum extent practicable. 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*

obligate funding when the contract is signed, but rather when a supply or service order is placed. Examples of IDVs include blanket purchase agreements, government-wide acquisition contracts, and indefinite delivery contracts.

[21] See Tables C4 and C5 for the 24 letter codes used to classify service categories and the 78 two-digit numerical codes used to classify product groups, respectively.

field to break down non-R&D contracts into *commercial contracts* and *noncommercial contracts*.[22] This allows us to explore how the effect of R&D contracts has changed over time as the government increased procurement of technologies with existing commercial applications and decreased procurement of technologies specifically designed to meet unique agency specifications.

## 4.3 Guaranteed Demand

Guaranteed demand refers to rewarding firms that demonstrate technological superiority in R&D races with downstream procurement. While federal agencies are generally required to use full and open competition in procurement, the Competition in Contracting Act of 1984 authorizes noncompetitive contracting under a limited number of exceptions. Notable among the exceptions are *follow-on contracts* for the continued development or production of a major system or highly specialized equipment, or (in the case of DoD, NASA, and the Coast Guard) for the continued provision of highly specialized services.[23] This legal framework allows the government to couple R&D races with downstream procurement by awarding follow-on contracts without competition. We use the *Extent competed* field to distinguish contracts that were awarded competitively from those awarded noncompetitively. This allows us to classify industries with above-median (below-median) shares of noncompetitive downstream procurement contracts (relative to other industries' shares in the same fiscal year) as industries with high (low) guaranteed demand.

## 4.4 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

[22] 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.

[23] FAR Section 6.302 limits these exceptions to circumstances when awarding follow-on contracts to any other source would likely result in (i) substantial duplication of cost that is not expected to be recovered through competition or (ii) unacceptable delays in fulfilling the agency's requirements.

agencies during 2001-2015 from USAspending.gov.[24] We match the names of grantees to our firm panel. We identify 456 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 the value of 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.

### 4.5 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). 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).

Procurement touches a broad set of R&D-performing firms. In our sample, 1% of firms are pure military contractors, 29% supply both military and nonmilitary needs, 27% are pure nonmilitary contractors, and 43% are noncontractors. Combined, 57% of firms receive at least one contract during 1980-2015, 23% receive at least one R&D contract during 1980-2015, and 10% receive at least one federal grant during 2001-2015.

Contractors are awarded an average of $111 million in contracts per year. Of those dollars, an average of $18 million are for R&D services, which is almost an order of magnitude larger than the annual grants received by grant recipient firms. On average, contractors receive contracts from 6 federal agencies (with a median of 4 agencies). Consistent with the premise that R&D contracts are the "ticket to play" in the government market, 80% of sample firms that win an R&D contract subsequently receive at least one noncompetitive downstream procurement contract during their remaining years in our sample. Among firms that never

[24] 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).

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 |

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.

win an R&D contract, only 35% receive at least one noncompetitive downstream procurement contract during their years in our sample.

There is substantial heterogeneity in contracts by awarding agency (see Table E8). The average value of an R&D contract ranges from $8,362 for the Federal Maritime Commission to $15,999,149 for the U.S. Agency for International Development. The average value of an R&D contract is $4.8 million for the DoD and $6.3 million for NASA. Typically, noncompetitive downstream procurement contracts from the DoD, NASA, DoE, and Department of Homeland Security (DHS) are larger than all downstream procurement contracts. This suggests that firms may have strong incentives to win R&D races from these agencies as pathways to guaranteed demand.

There is also heterogeneity in the characteristics of R&D contractors working for different agencies (see Table E2). 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 (see Tables E3 and E4). Regardless of R&D contract size, defense R&D contractors tend to also work for NASA (see Table E5). In addition, if a firm is an R&D contractor for a non-defense agency, it is also a defense R&D contractor. At the high end, 93% of DoC R&D contractors are defense R&D contractors as well. At the low end, 52%s of HHS R&D contractors are also defense R&D contractors. 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 (see Table F6). The two-digit industries (SIC2) most represented are Chemicals (796 firms), Electronic Equipment (680 firms), and Instruments (672 firms). We classify those industries into five main groups: Chemicals, Electronics, Instruments, Business services, and Others (see Table F7). The largest average annual R&D contracts are in the Others group ($45 million), while the smallest are in Chemicals ($1 million, see Table F8). 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 (see Figure F4). In 1994, just before the passage of the Federal Acquisition Streamlining Act, the industries with the highest share of R&D contracts in all contracts were the Others group (35%) and Instruments (23%). In 2015, the industries with the highest share of commercial contracts in all contracts were Chemicals (76%) and Electronics (38%).

The distribution of grants by awarding agency is also 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%).[25] Recipients are awarded an average of $1.9 million in grants per year (with a median of less than $0.1 million). The largest average annual grants are in the Others group ($4.5 million), while the smallest are in Business services ($0.6 million).

Table 2 presents mean comparison tests between the 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 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 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 (see Table F9).

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.

[25] By dollar value, 55% of awards are cooperative agreements, 33% are block, formula, or project grants, and 12% are direct payments.

# 5 Econometric Specifications

Our econometric analysis proceeds in three steps. First, we estimate the effect of R&D contracts on R&D expenditures, publications, and patents. Second, we explore the potential mechanism behind the effect. We examine whether the effect is strong (i) for firms in industries with high guaranteed demand, (ii) for larger firms, and (iii) when private market incentives to invest in science 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 and in the relationship between procurement contracts and firm scientific capabilities.

## 5.1 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 $Y_{i,t}$):

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

$R\&D\ contracts_{i,t-3}$ are R&D contracts awarded to focal firm $i$ in year $t-3$.[26] 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 $\epsilon$ 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 cus-

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

tomers). 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.[27] 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 or appropriability concerns due to weak patent rights (especially for scientific knowledge outside chemicals and life sciences). Guaranteed public demand can be a substitute for securing private returns to risky upstream R&D.

Conversely, there are several reasons why we expect no or little effect in the patent equation. First, guaranteed demand may reduce the need to exclude rivals via costly patenting. Second, some R&D contracts may prohibit patenting to protect sensitive technologies, though Howell et al. (2021) suggest that this is not a significant concern for most contractors. Third, private market incentives may already be stronger for technology development, rendering guaranteed demand less effective in driving downstream R&D.

#### 5.1.1 Identification Strategies

A major econometric challenge is how to deal with the endogeneity of contracts. Common shocks can affect both government procurement and corporate R&D activity. If the government targets firms that experience positive (negative) technology or demand shocks, then the OLS estimate of $\alpha_1$ is upward-biased (downward-biased).

We implement two strategies to mitigate this concern. Our first identification strategy is to construct several instrumental variables that exploit variation in industry-level procurement and agency-level windfall funding resulting from the congressional appropriations process to predict firm-level R&D contracts.

Our first instrument uses industry-level R&D contracts to predict firm-level R&D con-

[27] Independent company-funded 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 FAR Part 31. However, the firm still bears the risk of performing the R&D in hopes of recovering it from future contracts.

tracts. We follow Moretti et al. (2021) and build $Industry\ R\&D\ funding_{i,t} = (Industry\ R\&D\ contracts_{SIC3,t} - Firm\ R\&D\ contracts_{i,t}) \times Industry\ share_{SIC4,SIC3}$. Here, $Industry\ R\&D\ contracts_{SIC3,t}$ is the total value of all R&D contracts awarded by federal agencies to firm $i$'s SIC3 industry in year $t$. $Firm\ R\&D\ contracts_{i,t}$ is the value R&D contracts awarded to firm $i$ in year $t$. $Industry\ share_{SIC4,SIC3}$ is calculated by dividing the total value of R&D contracts awarded to firm $i$'s SIC4 industry during 1980-2015 by the total value of R&D contracts awarded to firm $i$'s higher-level SIC3 industry during 1980-2015.[28] Additional details about this instrument are included in Online Appendix D.

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 *requested* 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).[29] Demand for agency funding is a function of the common technology 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. 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.[30]

The requested budget may consider the bargaining power affecting the actual budget. To address this possibility, our third instrument exploits variation in DoD windfall funding. Due to its strong bargaining position, DoD's requested budget is more likely to be appropriated by

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

[29]Each annual *Budget of the U.S. Government* gives us two pieces of information on federal agency funding: the requested amount proposed by the agency and the actual amount appropriated by Congress. The difference between actual and requested amounts represents the windfall budget authority. We hand-collect this information on each of 12 main federal agencies, plus an "Other" category for smaller agencies.

[30]We build $Agency\ windfall\ funding_{i,t}$ 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 $t$. $Agency\ share_{SIC3,t,Agency}$ is calculated by dividing the total value of R&D contracts awarded by the focal agency to firm $i$'s SIC3 industry in year $t$ by the total value of R&D contracts awarded by the focal agency in year $t$.

Congress (e.g., in times of national defense emergencies) and thus affect the actual budgets 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.[31]

Our second identification strategy is to exploit a quasi-natural experiment around the collapse of the former Soviet Union. 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 DoD 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 massive reallocation of government procurement.[32] Between 1988 and 1992, DoD procurement obligations dropped 38%, while HHS obligations almost tripled (from a much smaller baseline).

Overall, public demand declined between 1988 and 1992. On average, industries experienced a $84 million reduction in procurement contracts. Yet, not all industries were equally affected (see Figure D2 and Table D6). 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).

[31] We build $DoD\text{-}predicted\ windfall\ funding_{i,t}$ by replacing $Windfall\ funding_{Agency,t}$ in the second instrument with $DoD\text{-}predicted\ windfall\ funding_{Agency,t}$. Here, $DoD\text{-}predicted\ windfall\ funding_{Agency,t}$ 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. 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.

[32] 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 R&D contracts from the DoD and examine the effect of R&D contracts from civilian 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.

Because the reallocation between industries was caused by geopolitical circumstances unrelated to technology shocks, we exploit the end of the Cold War as a quasi-natural experiment.

Our fourth instrument uses changes between the pre- and post- Soviet collapse periods in industry-level contracts to predict firm-level R&D contracts during 1995-2015 (see Figure D1 for the associated timeline). Because this instrument does not vary within firms (i.e., there is only one change per firm), we cannot use firm fixed effects. 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. Many 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 by each firm, we use the shares of firm sales in each industry as weights. We build $Cold\ War\ shock_i = \sum_{Industries} \Delta Contracts_{SIC4} \times Share\ of\ sales_{i,SIC4}$. Here, $Cold\ War\ shock_i$ is the instrument for firm $i$. $\Delta Contracts_{SIC4}$ is the difference between the average contracts awarded to the focal industry in the pre- (1986-1988) and post- (1990-1992) periods. $Share\ of\ sales_{i,SIC4}$ is the share of firm $i$'s sales during 1982-1985 in the focal industry, calculated using the Compustat Segments dataset.[33] We use a multi-year lag in calculating shares 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 and exited industries where they anticipated shrinking procurement.

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 procurement during 1990-1994, but were otherwise not affected by the end of the Cold War. we examine firms in

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

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 is a year-over-year change in procurement contracts awarded to the industry that is in the top quintile of the distribution of changes between 1990 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 1990 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 $Sales - All\ contracts$), *Publications*, and *Patents*, respectively, for firm $i$ in year $t$. Leads and lags are indicator variables 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 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 $\epsilon$ 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 1990-1994 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

[34] Using high-level, two-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 1990-1994 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.

remain treated for the complete duration of the sample. We assume there is no anticipation.[36]

## 5.2 Trends in the Composition of Contracts

We estimate the following specification for trends in the value and composition of 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 4, 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 this specification are as previously described.

We are interested in the estimate of $\beta_1$. 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. These predictions are consistent with increased procurement of technologies with existing commercial applications and decreased procurement of technologies specifically designed to meet unique agency specifications.

[36] Consistent with this assumption, we find that treated and control firms follow parallel trends prior to the shock.

## 5.3 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:

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

$Contracts_{i,t}$ 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. The other elements of this specification are as previously described.

We are interested in the estimate of $\gamma_3$ 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 the government has increasingly decoupled R&D races from downstream procurement.

# 6 Estimation Results

## 6.1 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* is positively related to *R&D contracts* (p-value <0.01).[37] Our coefficient estimate on R&D contracts is smaller than the 0.011 reported by Moretti et al. (2021) when estimating the effect of government-financed R&D (which includes both

[37]Results are not sensitive to how we control for firm size. In unreported specifications, we obtain the same coefficient estimate on *R&D contracts* when we use *R&D stock* as a size control and a coefficient estimate on *R&D contracts* of 0.012 when we drop the size control altogether.

R&D contracts and grants) on company-funded R&D using a panel of French firms.[38] Unlike Moretti et al. (2021), we estimate the effect of R&D contracts separate from the effect of grants. Unlike Wallsten (2000), we estimate the effect of R&D contracts on large(er) publicly listed firms, not resource-constrained small firms.

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)$_{t-1}$ | 0.006 | 0.045 | 0.073 | 0.066 | 0.342 |
| | (0.002) | (0.021) | (0.024) | (0.023) | (0.131) |
| ln(Sales)$_{t-1}$ | 0.404 | 0.387 | 0.383 | 0.384 | 0.360 |
| | (0.016) | (0.016) | (0.016) | (0.016) | (0.017) |
| ln(Pre-sample mean R&D expenditures) | | | | | 0.357 |
| | | | | | (0.084) |
| 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) | | 108.23 | 100.69 | 101.62 | 10.59 |
| Firms | 4,214 | 4,157 | 4,106 | 4,120 | |
| Observations | 47,730 | 44,556 | 43,129 | 43,309 | 4,884 |
| Adjusted R-squared | 0.917 | 0.166 | 0.142 | 0.148 | 0.324 |

*Notes:* This table presents the estimation results for the relationship between R&D contracts and R&D expenditures. Columns 2-5 present the second stage of 2SLS, where 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.

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, obtaining an F-statistic of 50 (see Column 1 in Table D7). In the second stage, we regress *R&D expenditures* against the predicted R&D contracts. As expected, $\hat{\alpha}_1 > 0$. The 2SLS estimate is statistically significant (p-value $<0.05$) and larger than OLS, suggesting that contracts might target fields affected by negative technology or

[38] In an unreported specification, we drop the control for *Sales* and cluster standard errors at the SIC3 level to more closely match their specification. We obtain a coefficient estimate of 0.012.

demand shocks.[39] Evaluated at the sample means, the estimate indicates that a $1 million increase in R&D contracts crowds in $0.36 million in company-funded R&D expenditures.[40] In Table G11, we exclude contracts from the seven largest agencies one by one and find that our results are not driven by the DoD or another large 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 statistically significant (p-value <0.01) and sightly larger.

In Column 5, we exploit the *Cold War shock* as a quasi-natural experiment for exogenous changes in government procurement from various industries. In the first stage, we predict *R&D contracts* awarded to a focal firm using our instrument (see Column 2 in Table D7) and obtain an F-statistic of 103. In the second stage, we regress *R&D expenditures* against the predicted R&D contracts. Because this 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 <0.01).

In summary, the causal estimates suggest that R&D contracts "crowd in" company-funded R&D investments. This result is in line with the prior literature (e.g., Moretti et al., 2021).

## 6.2 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]

[39] Government procurement indeed aims to maintain the existing military-industrial base (Peters, 2021). For example, in 1994, the U.S. Congress appropriated $2.5 billion for the Defense Reinvestment and Conversion Initiative, a transition assistance program for industries affected by post-Cold War reductions in defense spending (U.S. Government Accountability Office, 1997).

[40] Average values for R&D expenditures and R&D contracts are $94.2 million and $11.7 million, respectively. The marginal effect of an additional $1 million in R&D contracts is $0.045(94.2 + 0.000001)/(11.7 + 0.000001) = 0.36$ million in additional company-funded R&D expenditures.

[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

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) |
| ln(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. Columns 2-6 present the second stage of 2SLS, where 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.

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*, respectively, as the instrumental variable. Evaluated at the sample means, the coefficient estimate in Column 3 suggests that \$14.7 million in additional R&D contracts lead to one additional publication.[42] Once again, 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 esti-

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

mates from Columns 2-4, for three reasons. The set of firms differs across approaches.[44] Our first three instruments may not fully resolve the downward bias in OLS because they rely on time-invariant exposure shares that could still be correlated with firm-specific, time-invariant heterogeneity. Alternatively, 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 (see Figure 7).

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. We weight each publication by the number of citations received from other publications.[45] This gives us a quality-adjusted measure of upstream R&D. The coefficient estimate suggests that firms are not simply increasing the number of publications while lowering their quality in response to winning R&D contracts (p-value $<0.05$).

In summary, we find evidence supporting the view that R&D contracts drive upstream R&D, as measured by corporate publications. The analyses included in Online 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.

## 6.3 Patent Equation

Table 5 presents the 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

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 1980-1988 and exposure to sales from various industries during 1982-1985. The actual regressions use data for 1995-2015. The range in coefficient estimates likely reflects 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) guaranteed public demand.

[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).

<0.001).[46]

Estimation results using *Industry R&D funding*, *Agency windfall funding*, *DoD-predicted windfall funding*, and the *Cold War shock*, respectively, as the instrumental variable are included in Columns 2-5. 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 three potential explanations for this result. First, guaranteed public demand may reduce the need to exclude rivals through patenting. Second, the government may restrict patenting due to disclosure concerns. Third, private market incentives are likely to be stronger for technology development, rendering guaranteed public demand less effective.

Table 5: Estimation Results for the Patent Equation

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | ln(Patents) | | | | | ln(Citation-weighted 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) |
| ln(Pre-sample mean patents) | | | | | 0.416 | |
| | | | | | (0.046) | |
| 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. Columns 2-6 present the second stage of 2SLS, where 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.

In Column 6, we use a quality-adjusted measure of downstream R&D. Specifically, we

[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.

weight 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 R&D contracts drive firms to invest in downstream R&D, as measured by patents. In light of our publication equation results, this highlights the importance of distinguishing between scientific research ("R") and downstream development ("D") in corporate R&D.[48]

### 6.4 Event Study Analysis: The End of the Cold War

Figure 3 presents results from the Cold War event study. 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). 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 do not 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 do not 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

[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).

[48] Finding no effect for patents may seem inconsistent with the prior literature. However, prior studies either focus on estimating the effect of grants on patents (e.g., Azoulay et al., 2019; Howell, 2017) or study the effect of SBIR contracts on small-firm patents (e.g., Howell et al., 2021). Due to the fundamental differences between grants and R&D contracts, the resource-constrained nature of small firms, and inefficiencies in transferring knowledge between firms (Atalay et al., 2014), guaranteed demand should not be in play in these settings. Conversely, we estimate the effect of R&D contracts on large-firm patents, a setting that is well-suited for investigating the guaranteed demand mechanism.

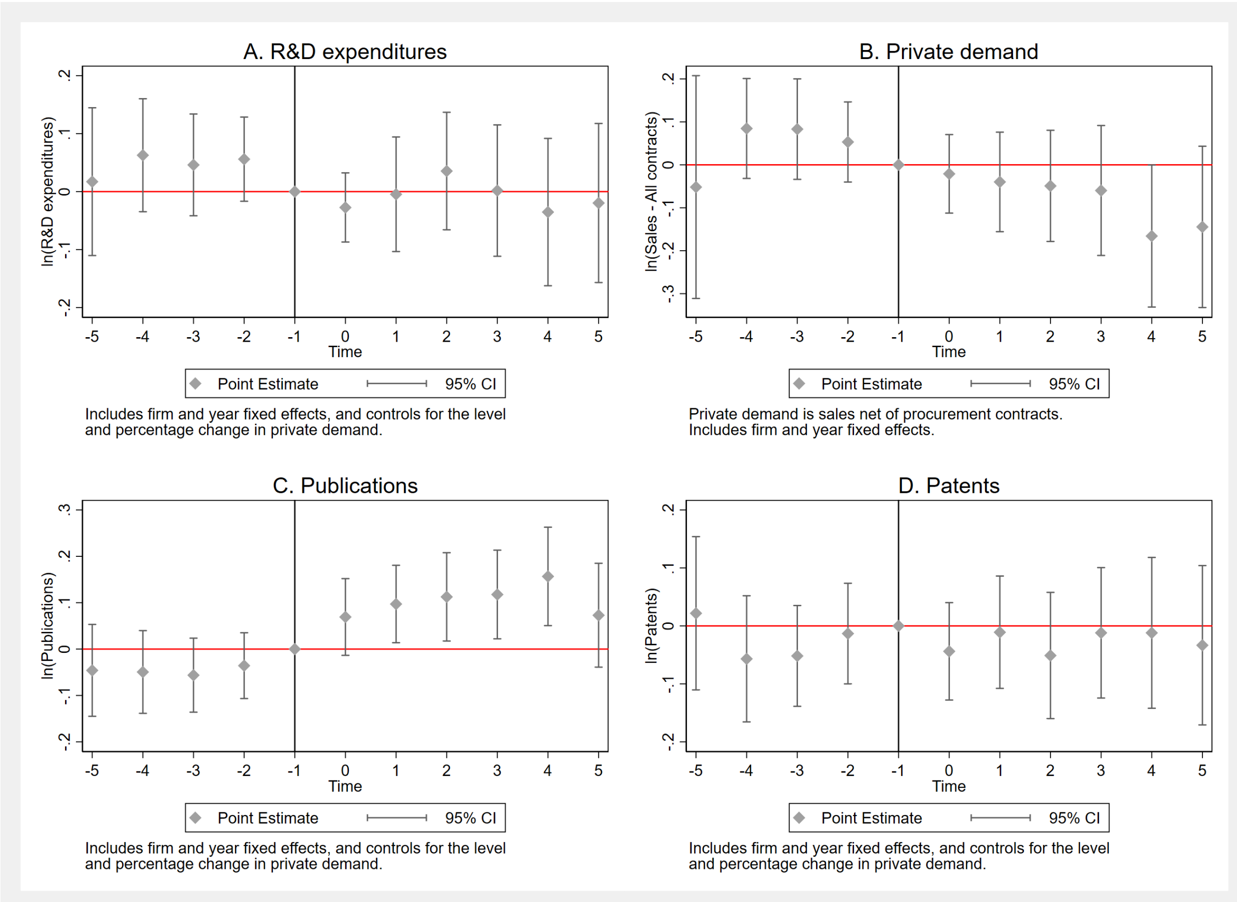


Figure 3: Event Study Around the End of the Cold War

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.

in constructing our event study sample. Panel C indicates that treated firms increase their publishing after the procurement shock, consistent with the 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 R&D contracts on corporate publications and patents.

## 6.5 R&D Contracts as a "Ticket" to Downstream Procurement

We explore the guaranteed demand mechanism by estimating how the effect of R&D on upstream and downstream corporate R&D varies by industry guaranteed demand, firm size, and private market incentive to invest in science.

### 6.5.1 Industry Guaranteed Demand

In Table 6, we examine how the effect of R&D contracts on publications and patents varies by industry guaranteed demand, where high guaranteed demand industries have above-median shares of noncompetitive downstream procurement contracts. Columns 1-4 show results from the second stage of 2SLS regressions using *Industry R&D funding* to instrument for *R&D contracts*. Consistent with the premise that R&D contracts are the "ticket to play" in the government market, the effect of R&D contracts on publications is strong for firms operating in high guaranteed demand industries (Column 1, p-value $<0.05$).[49]

Columns 5-7 present within-firm OLS estimation results for the relationship between winning R&D contracts and future downstream procurement. The coefficient estimates in Columns 5 and 7 show that winning R&D contracts is positively associated with the value of future downstream procurement contracts (p-values $<0.001$), while winning grants is not (Column 6). Table G18 indicates that our results are robust to using different measures of future procurement contracts.

### 6.5.2 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.[50] What large firms need is a market to sell the

[49]In unreported specifications, we obtain similar results when we control for quality by weighing each publication by the number of citations received from other publications.

[50]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.

Table 6: Variation by Industry Guaranteed Demand

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | ln(Publications) | | ln(Patents) | | ln(Noncompeted downstream procurement contracts) | | |
| | High guaranteed demand (IV: Industry R&D funding) | Low guaranteed demand (IV: Industry R&D funding) | High guaranteed demand (IV: Industry R&D funding) | Low guaranteed demand (IV: Industry R&D funding) | Contract indicator (OLS: Within) | Grant indicator (OLS: Within) | Contract and grant indicators (OLS: Within) |
| ln(R&D contracts)$_{t-3}$ | 0.042 | 0.017 | -0.015 | 0.007 | | | |
| | (0.021) | (0.026) | (0.026) | (0.036) | | | |
| ln(R&D stock)$_{t-3}$ | 0.130 | 0.096 | 0.269 | 0.211 | | | |
| | (0.015) | (0.011) | (0.023) | (0.015) | | | |
| [Has R&D contracts = 1]$_{t-1}$ | | | | | 1.610 | | 1.607 |
| | | | | | (0.158) | | (0.158) |
| [Has grants = 1]$_{t-1}$ | | | | | | 0.205 | 0.135 |
| | | | | | | (0.179) | (0.174) |
| ln(R&D stock)$_{t-1}$ | | | | | 0.328 | 0.346 | 0.328 |
| | | | | | (0.051) | (0.052) | (0.051) |
| Sample years | 1980-2015 | 1980-2015 | 1980-2015 | 1980-2015 | 1980-2015 | 1980-2015 | 1980-2015 |
| Firm fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 20,012 | 20,388 | 20,012 | 20,388 | 52,886 | 52,886 | 52,886 |
| Adjusted R-squared | 0.010 | 0.018 | 0.064 | 0.060 | 0.711 | 0.709 | 0.711 |

*Notes:* This table presents results from estimating how the effect of R&D contracts on publications and patents varies by industry guaranteed demand. The *High guaranteed demand* sample includes firms in industries with above-median shares of noncompetitive downstream procurement contracts. The *Low guaranteed demand* sample includes firms in industries with below-median shares of noncompetitive downstream procurement contracts. Columns 1-4 present the second stage of 2SLS, where R&D contracts are instrumented using *Industry R&D funding*. Columns 5-7 present within-firm OLS estimates. One is added to logged variables. Standard errors (in parentheses) are clustered at the firm level.

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.[51]

[51] 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.

Table 7: Variation by Firm Size

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | ln(Publications) | | ln(Patents) | |
| | Small firms | Large firms | Small firms | Large firms |
| ln(R&D contracts)$_{t-3}$ | 0.004 | 0.054 | -0.053 | -0.007 |
| | (0.024) | (0.024) | (0.032) | (0.028) |
| ln(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.

### 6.5.3 Market Incentives to Invest in Science

Guaranteed public demand should be more important when private market incentives to invest in science are insufficient. Therefore, we expect R&D contracts to have a strong effect on publications that (i) are not cited by the firm's own patents (the science is missing downstream applications), (ii) are cited by rival firms' patents (the science spills over to product-market competitors), and (iii) are not protected by the firm's own patents (the science is harder to appropriate).[52]

Table 8 presents estimation results from the second stage of 2SLS regressions using *Industry R&D funding* to instrument for *R&D contracts*.[53] Columns 1 and 2 compare the effect on publications with and without downstream applications inside the inventing firm. The coefficient estimates indicate that the effect is strong when the science does not have

[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 Online Appendix C.

internal use (p-value <0.05 in Column 2).

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. The coefficient estimates indicate that the effect is strong when rival patents cite the firm's publications (p-value <0.01 in Column 4).[54]

The last two columns compare the effect on publications with low vs. high protection from the firm's own patents. 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).[55]

Table 8: 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.

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.

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

[55]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.

## 6.6 Changes Over Time

We have shown that firms invest in scientific research to increase their chances of landing lucrative downstream procurement contracts with the government. Yet, this effect has weakened over time as procurement policy changes implemented throughout the 1980s and 1990s (as summarized in Online Appendix A) have increasingly decoupled R&D contracts from downstream procurement.

Figure 4 shows that the share of R&D contract dollars in all contracts has fallen from a high of 29% in 1994 to 10% in 2015 (solid line). At the same time, the share of commercial contract dollars in all contracts has increased from 0% in 1994 to 14% in 2015 (dashed line).[56] These temporal changes have occurred across a wide range of industries (see Figure F4). To the extent that public markets may have become more similar to private markets (e.g., by acquiring technologies that have achieved commercial success rather than new technologies that meet unique government requirements and specifications), their ability to substitute for weak market incentives to invest in risky scientific research may have decreased.

That is not to say that downstream procurement itself has become less important. Another way to look at the shrinking share of R&D contracts is to note that downstream procurement per R&D contract dollar has increased substantially over the past two decades, as shown in Figure 5. However, this growing prize has become more likely to be awarded through competition.

Historically, the government awarded a majority of procurement contracts without competition, providing guaranteed demand to firms that demonstrated strong technical capabilities.[57] Over time, pressures to reduce cost and increase efficiency and transparency have led to legislative mandates to use competition whenever practicable (Manuel, 2011). Figure 6 shows that the share of competitive contract dollars in all contracts has increased from 36%

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

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

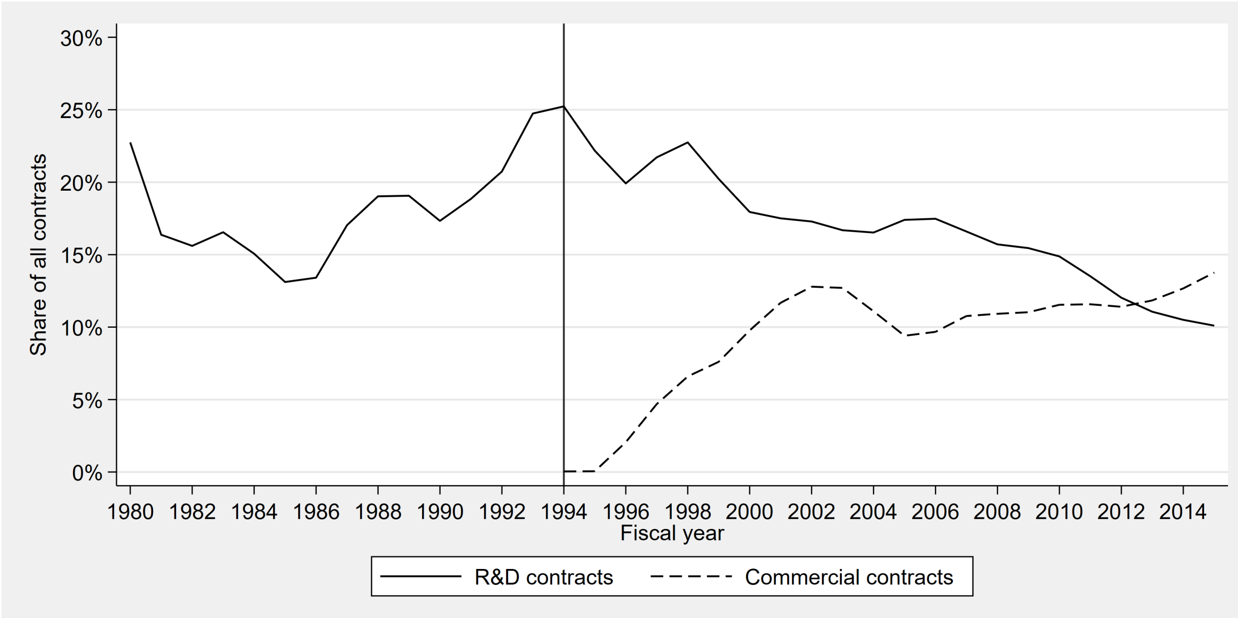


Figure 4: Share of R&D Contracts in All Contracts Over Time

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.

in 1980 to 68% in 2015. At the same time, the share of noncompetitive product contracts has dropped from 78% in 1980 to 49% in 2015.

Winning large procurement contracts no longer requires scientific capabilities. Figure 7 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 et al. (2018) document a decline in the stock market value and the mergers and acquisitions (M&A) value of scientific capabilities. We show that corporate scientific capabilities have fallen out of favor with the U.S. government as well.

In summary, Figures 4-7 highlight three changes over time: (i) the decreased importance

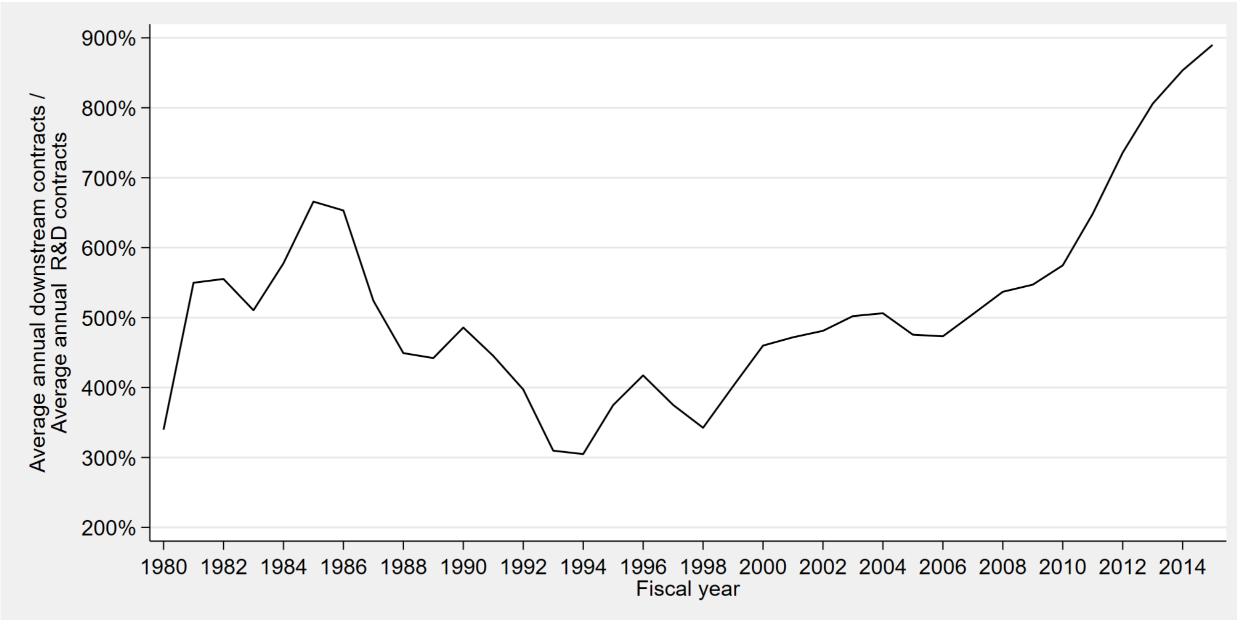


Figure 5: Ratio of Downstream Contracts to R&D Contracts Over Time
This figure plots the ratio between the annual value of downstream contracts and the annual value of R&D contracts awarded to contractor firms in our sample over time.

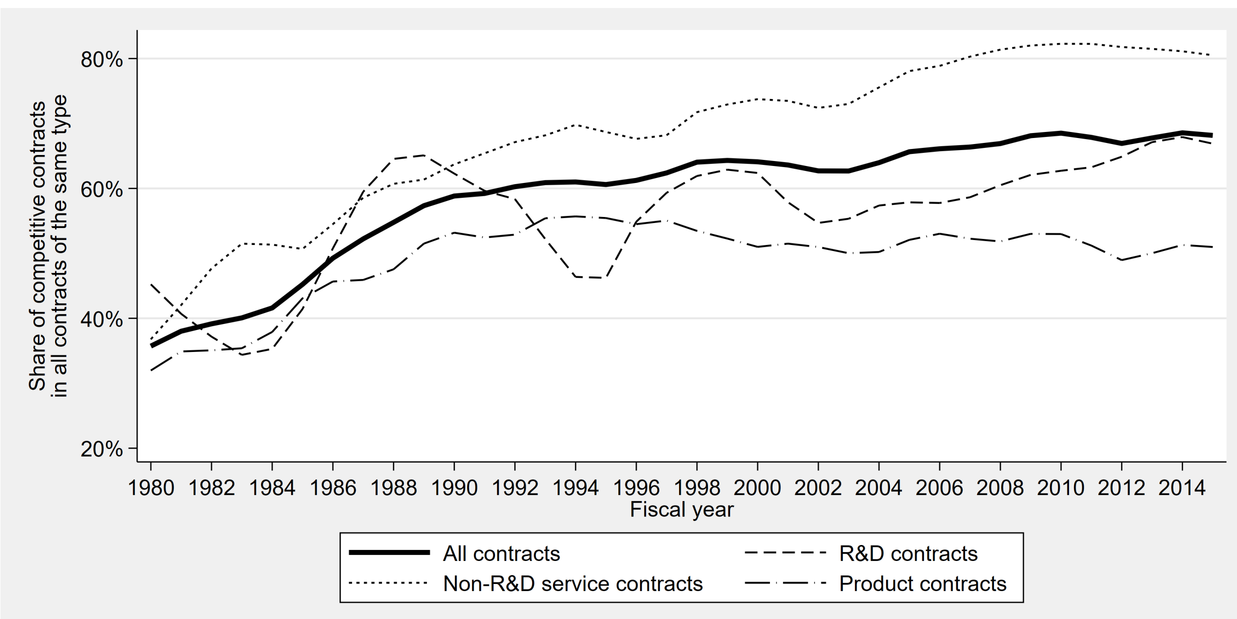


Figure 6: Share of Competitive Contracts in All Contracts Over Time
This figure presents the trend in the share of competitive contract dollars in all contracts of the same type obligated by federal agencies to all recipients (not limited to our sample firms). Competitive contracts are awarded using full and open competition.

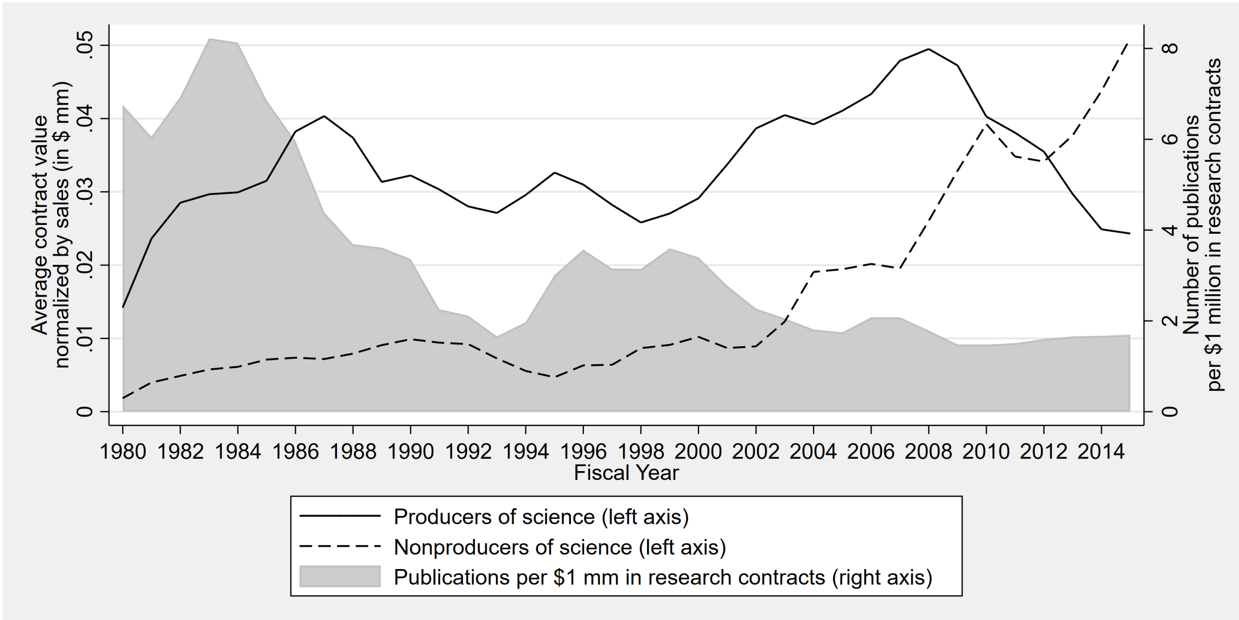


Figure 7: Average Contract Value Over Time

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).

of R&D races, (ii) the rise in competitive procurement, and (ii) the larger allocation of contracts to firms that do not participate in scientific research. To help us understand their implications for incumbent firms, Table 9 presents within-firm OLS estimates for changes in procurement contract value and composition, as well as the relationship between total contracts and firm scientific capabilities, over time. Column 1 shows that total contract size has increased by 34% per decade (p-value <0.05).[58]

Columns 2 and 3 show that the increase in procurement value was driven by non-R&D contracts and commercial contracts. The coefficient estimates imply that the annual value of R&D contracts decreased by 12% per decade (p-value <0.05), while the annual value of

[58]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.

commercial contracts more than doubled per decade (p-value <0.001).[59]

Column 4 shows that the share of R&D contract dollars in all contracts has remained unchanged. This suggests that the downward trend in Figure 4 was driven by entry from nontraditional contractors that perform less corporate R&D.[60] Meanwhile, Column 5 shows that the share of commercial contracts in all contracts increased by 24% per decade between 1995 and 2015 (p-value <0.001).

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 interaction coefficient (p-value <0.001).[61]

In summary, the evidence presented in this table is consistent with the government having significantly decoupled R&D races from downstream procurement, which would have eroded its ability to incentivize upstream corporate R&D through the guaranteed demand mechanism.

# 7 Discussion and Conclusion

This paper provides evidence suggesting that the anticipation of downstream government procurement encourages corporations to invest in upstream R&D. We document a positive effect of R&D contracts on publications ("R") and show that the effect is strong when downstream procurement is awarded without competition, for larger firms, and when private market incentives are relatively weak. We also show that the effect was stronger before the mid-1990s, when policy reforms such as the Federal Acquisition Streamlining Act of 1994 changed the composition of procurement contracts and significantly decoupled R&D races

[59] 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.

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

[61] As Tables G20 and G21 show, these changes are present across all industries and are robust to considering different firm subsamples and nonlinear time effects.

Table 9: 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.

from downstream procurement.

With the above findings, we make two main contributions. First, we help explain *why* corporations are withdrawing from scientific research. In recent decades, the composition of corporate R&D has shifted away from research and toward development. The share of research dollars in business R&D has dropped from a high of 31% in 1986 to 20% in 2015.[62] Concurrently, adjusting for firm size, the annual number of corporate publications has declined (Arora et al., 2021) and the market value attributed to firm scientific capabilities (i.e., the "shadow price" of scientific publications) has fallen (Arora et al., 2018). Investors value corporate research less today than in the past. Similarly, managers are willing to pay less for the scientific capabilities of their acquisition targets today than in years prior. Federal acquisition professionals appear to have joined their ranks. We show that publications have

[62] Data are from Tables 2, 3, and 4 of the National Patterns of R&D Resources series from the National Science Foundation (NSF).

become less important for downstream procurement. By decoupling R&D races from downstream 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, Van Reenen, & Williams, 2019; Edler & Georghiou, 2007; Mowery, 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 downstream procurement to boost domestic economic activity and support targeted geographies or industries.[63] To the best of our knowledge, this paper is the first to demonstrate the effect of government procurement on upstream and downstream corporate R&D. This link between corporate R&D investment and downstream government procurement is one important way in which demand-side policies are different from supply-side policies (e.g., grants and tax subsidies).

We highlight two promising avenues for future work. The first explores the conditions under which it is efficient to couple R&D races with downstream procurement (i.e., rewarding the firm that developed the upstream technology with the downstream implementation contract). Decoupling R&D from production may lead to inefficiencies in project implementation if there is a high degree of complementarity between R&D and production. In addition, if the government faces contractual problems due to, for instance, the transfer of tacit knowledge and asymmetric information, decoupled projects may be harder to implement (Che et al., 2021). On the other hand, if contractual problems also exist between firms, then R&D specialists cannot easily partner with downstream producers. In that case, decoupling may increase efficiency if the government subsidizes R&D and then makes it available for downstream firms. The question then becomes how to trade off the benefits from specialization against the costs from coordination and contracting.

[63] 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.

The second promising direction for future research examines the effect of government procurement on small firms. This effect operates through two main channels. The first is direct, in the form of procurement policies that target small firms through set-asides and subcontracting requirements.[64] The second is indirect, in the form of investments by large firms that wish to use startup technology to land lucrative downstream procurement contracts.[65] Studying the implications of government procurement regimes on small firms would deepen our understanding of the effect of public demand on the American innovation ecosystem as a whole.

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[64] The 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.

[65] 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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# ONLINE APPENDIX

# 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).[66] 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.[67] In response, interested firms prepare and submit offers.[68] Agency personnel then evaluate the offers using the source selection method and criteria described in the solicitation, in accordance with the Federal Acquisition Regulation (FAR).[69] The agency awards a contract to a firm only after determining that the company is responsible, meaning

[66] 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.

[67] 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 GSA schedule. For R&D contracting, firms can also submit unsolicited proposals or compete in government-sponsored challenges and prize competitions.

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

[69] Almost all federal contracting is governed by the FAR, which consists of Parts 1-53 of Title 48 of the Code of Federal Regulations. The two primary methods of source selection are sealed bidding and negotiated contracting. The latter is typically used for R&D contracts.

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.

## 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 (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 (DoD) 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. 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 General Services Administration (GSA) 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.[70] 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.[71] 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.[72] 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.[73]

We supplemented these data with historical contract transactions from SAM.gov, a website managed by the GSA. 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.[74] The FPDS provides a list of 6,725

[70] 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.

[71] 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.

[72] 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.

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

[74] 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.

contracting offices that were active and valid as of November 2, 2020. 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 contracts awarded during fiscal years 1980-2015 by 72 different federal agencies.[75] 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).[76] Specifically, we performed 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.

[75] 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.

[76] 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.

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 subsidiary names. Overall, we matched 47% 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 2,590 firms (i.e., ultimate owners) that received a total of $5.9 trillion in procurement contract obligations during 1980-2015. Table B2 displays the largest contractors (by total value of contracts won) in each decade covered by our sample, while Table F6 presents the distribution by two-digit SIC code.

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% | 55% |
| Air Force | 2,108,521 | 21% | 68% |
| Navy | 2,578,467 | 14% | 69% |
| Army | 2,527,795 | 10% | 42% |
| Missile Defense Agency (MDA) | 83,913 | 45% | 97% |
| Defense Threat Reduction Agency (DTRA) | 23,791 | 57% | 45% |
| Defense Adv. Res. Proj. Agency (DARPA) | 13,895 | 91% | 56% |
| Other DoD | 1,285,012 | 1% | 26% |
| Energy, Department of | 933,972 | 7% | 34% |
| National Aeronautics and Space Admin. | 489,721 | 41% | 60% |
| General Services Administration | 296,698 | <1% | 23% |
| Health and Human Services, Department of | 271,837 | 19% | 34% |
| Veterans Affairs, Department of | 267,241 | <1% | 33% |
| Homeland Security, Department of | 170,631 | 5% | 30% |
| Transportation, Department of | 130,353 | 13% | 31% |
| Treasury, Department of the | 128,966 | 1% | 17% |
| Justice, Department of | 128,115 | 2% | 22% |
| State, Department of | 112,745 | 1% | 24% |
| 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% | 9% |
| Environmental Protection Agency | 40,987 | 6% | 15% |
| Education, Department of | 36,075 | 7% | 32% |
| Office of Personnel Management | 26,331 | <1% | 9% |
| Housing and Urban Development, Dept. of | 24,869 | 4% | 21% |
| Social Security Administration | 20,111 | <1% | 41% |
| 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% | 18% |
| National Archives and Records Admin. | 2,955 | <1% | 27% |
| Small Business Administration | 2,075 | 1% | 23% |
| Peace Corps | 1,893 | 14% | 11% |
| United States Agency for Global Media, BBG | 1,764 | <1% | 17% |
| Equal Employment Opportunity Commission | 1,676 | <1% | 7% |
| Federal Communications Commission | 1,258 | 1% | 12% |
| Executive Office of the President | 1,175 | 1% | 36% |
| Federal Trade Commission | 822 | 1% | 35% |
| 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 | 0% | 22% |
| National Gallery of Art | 394 | 38% | 2% |
| Government Accountability Office | 382 | 10% | 8% |

This table displays federal agencies that awarded procurement contracts during 1980-2015. Contracts are deflated using the GDP Implicit Price Deflator to reflect millions of constant 2012 dollars (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% | 6% |
| J. F. Kennedy Center for the Performing Arts | 248 | 0% | 3% |
| Consumer Financial Protection Bureau | 214 | 0% | 7% |
| National Transportation Safety Board | 128 | 1% | 27% |
| United States Trade and Development Agency | 125 | 54% | 4% |
| Federal Election Commission | 119 | 1% | 14% |
| Export-Import Bank of the U.S. | 109 | 2% | 6% |
| International Trade Commission | 108 | <1% | 17% |
| Overseas Private Investment Corporation | 90 | 1% | 6% |
| National Mediation Board | 71 | 0% | 6% |
| National Endowment for the Humanities | 66 | 0% | 12% |
| Merit Systems Protection Board | 45 | 8% | 11% |
| Defense Nuclear Facilities Safety Board | 44 | 10% | 3% |
| Federal Housing Finance Agency | 29 | 0% | 4% |
| National Endowment for the Arts | 27 | 2% | 17% |
| Selective Service System | 25 | 0% | 14% |
| The Institute of Museum and Library Services | 17 | 0% | 7% |
| Federal Maritime Commission | 15 | 0% | 36% |
| 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% | 9% |
| Chemical Safety and Hazard Investigation Board | 7 | 0% | 8% |
| Occupational Safety and Health Review Commission | 5 | 16% | 18% |
| Committee for Purchase From People Who Are Blind or Severely Disabled | 4 | 0% | 9% |
| Election Assistance Commission | 2 | 24% | 19% |
| Office of Special Counsel | 2 | 27% | 41% |
| Library of Congress | 2 | 0% | 28% |
| American Battle Monuments Commission | 0 | 0% | 50% |
| Other | 357,695 | 4% | 21% |
| Total | 12,456,862 | 12% | 47% |

This table displays federal agencies that awarded procurement contracts during 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 millions of constant 2012 dollars (U.S. Bureau of Economic Analysis, 2021).

## Table B2: 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 | 63,010 | 11,349 | 98,814 | 2,298 | 750 | 882 |
| 1990 | McDonnell Douglas | 59,174 | 13,849 | 157,802 | 4,248 | 803 | 274 |
| 1990 | Raytheon | 52,306 | 12,083 | 173,796 | 4,939 | 1,247 | 1,127 |
| 1990 | General Electric | 40,905 | 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 | 305,637 | 54,714 | 667,733 | 32,370 | 2,387 | 3,838 |
| 2000 | Northrop Grumman | 178,131 | 39,024 | 289,648 | 5,413 | 1,373 | 2,287 |
| 2000 | General Dynamics | 167,173 | 25,414 | 233,535 | 3,807 | 567 | 322 |
| 2000 | Raytheon | 112,727 | 23,994 | 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 | 68,838 | 4,803 | 96,598 | 2,784 | 115 | 327 |
| 2000 | General Electric | 32,018 | 3,399 | 1,711,577 | 29,423 | 6,321 | 12,789 |
| 2000 | McKesson | 28,536 | 2 | 907,573 | 2,694 | 89 | 34 |
| 2000 | Honeywell International | 27,435 | 1,588 | 322,527 | 12,423 | 1,685 | 6,259 |
| 2010 | Lockheed Martin | 256,816 | 49,317 | 274,906 | 4,088 | 1,241 | 2,352 |
| 2010 | Boeing | 150,209 | 21,033 | 483,246 | 20,721 | 1,167 | 5,007 |
| 2010 | General Dynamics | 128,910 | 5,179 | 189,298 | 2,656 | 274 | 174 |
| 2010 | Raytheon | 84,775 | 13,891 | 143,825 | 3,606 | 1,084 | 2,205 |
| 2010 | United Technologies | 71,510 | 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 | 52,370 | 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 | 18,663 | 454 | 223,770 | 10,579 | 872 | 6,607 |

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).

# 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 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 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 C3 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.[77] As of 2020, 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, and then link NAICS industries to SIC industries using the concordances available from the U.S. Census Bureau. 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).[78] 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,

[77] The FSC is a government-wide commodity classification system designed for grouping, classifying, and naming all personal property items.

[78] 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 C3: Variable Crosswalk

| 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 SAM.gov and variables available for 2001-2020 from USAspending.gov.

- 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,
    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 C4: 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 |

*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 also use the *Product or service code* field to categorize DoD contracts as military or nonmilitary. We manually assign each two-digit service category or product group to either the military or the nonmilitary category based on their descriptions in the FPDS Product and Service Codes Manual (U.S. General Services Administration, 2021).

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).

We use the *Commercial items acquisition procedures* field to split non-R&D contracts into commercial contracts vs. noncommercial contracts.[79] Contracts were awarded using commercial 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. 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.[80] We aggregate competed and total contracts by year and contract type to produce the trend lines in Figure 6.

[79] This field indicates whether the solicitation used the special requirements for the acquisition of commercial items, supplies, or services. Those requirements are intended to more closely resemble the commercial markets as defined by the Federal Acquisition Regulation Part 12.

[80] 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 (as of March 2020).

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 (as of March 2020). Groups 21, 27, 33, 50, 57, 64, 82, 86, 90, 92, 97, and 98 are 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 $i$th word stem appears throughout the claims section of patents, $p_i$ is the number of patent documents that contain the $i$th 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.[81] 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

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

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:

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

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.[82] 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*.

[82] 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 (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 technology shocks). 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). Doing so lowers the power of our instrument in the first stage, but increases its validity.

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 the U.S. Defense Logistics Agency to identify the NAICS code. Then, we use the NAICS-to-SIC concordances available from the U.S. Census Bureau 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.

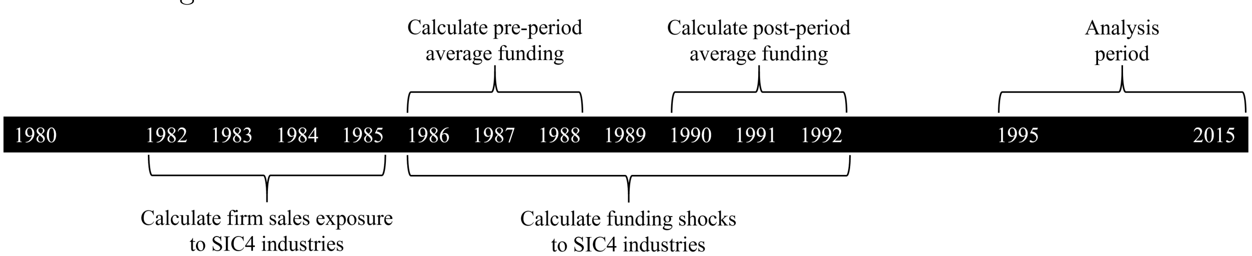
Take Boeing as an example. In 2012, Boeing's SIC3 industry ("372 Aircraft and parts") received \$13.7 billion in R&D contracts, including almost \$3.6 billion for Boeing. Over the sample period of 1980-2015, Boeing's SIC4 industry ("3721 Aircraft") received 99% of the R&D contracts awarded to its SIC3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

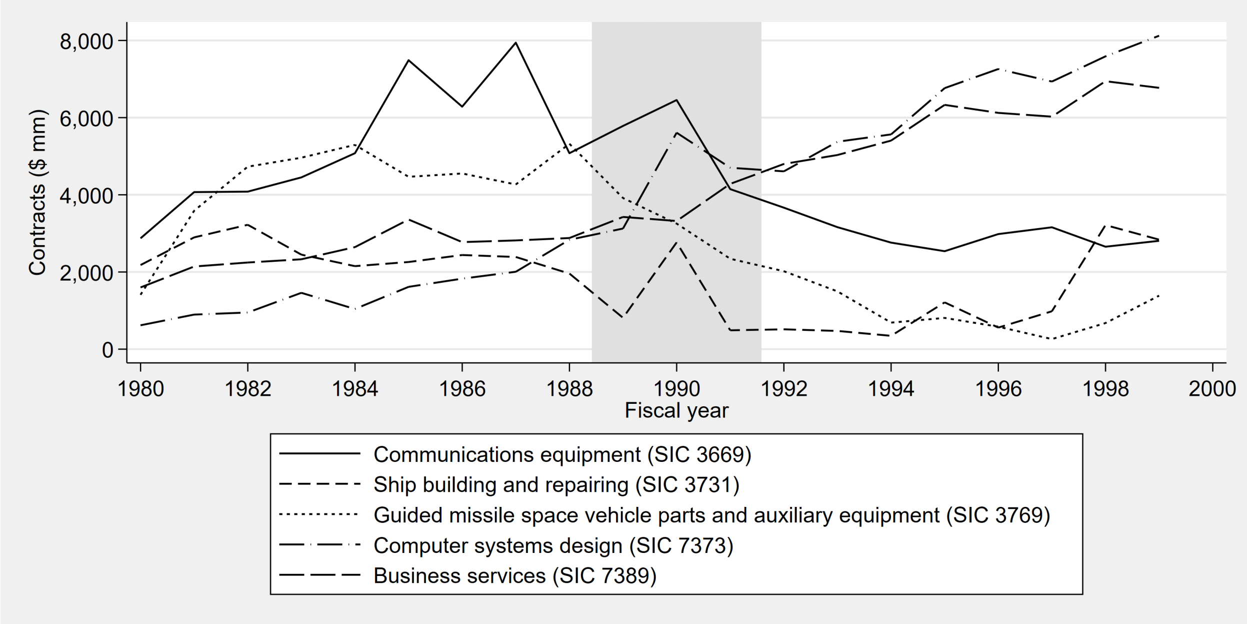
Figure D1 presents the timeline used for estimating the *Cold War shock* instrumental variable. Figure D2 and Table D6 present comparisons of procurement contracts awarded to various industries in 1988 and 1992.

Figure D1: The Cold War Identification Strategy Timeline




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

Figure D2: 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).

Table D6: 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. Observations are sorted in descending order of the difference between 1992 and 1988.

## D.3 First Stage Results

Table D7 shows the first stage results of the two-stage least squares (2SLS) instrumental variable estimations reported in this paper.

Table D7: Instrumental Variable Estimation (First Stage)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | ln(R&D contracts)$_{t-3}$ | | | | | |
| | Industry R&D funding | Agency windfall funding | DoD-predicted windfall funding | Cold War shock for R&D | Cold War shock for pubs | Cold War shock for pats |
| ln(Industry R&D funding)$_{t-3}$ | 0.072 | | | | | |
| | (0.007) | | | | | |
| ln(Agency windfall funding)$_{t-3}$ | | 0.070 | | | | |
| | | (0.007) | | | | |
| ln(DoD-predicted windfall funding)$_{t-3}$ | | | 0.073 | | | |
| | | | (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 | 0.029 | 0.034 | 0.111 | 0.125 | 0.195 |
| | (0.030) | (0.030) | (0.030) | (0.042) | (0.027) | (0.029) |
| Sample years | 1980-2015 | 1980-2015 | 1980-2015 | 1995-2015 | 1995-2015 | 1995-2015 |
| Firm fixed effects | Yes | Yes | Yes | No | No | No |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 41,047 | 39,767 | 39,913 | 5,514 | 5,861 | 5,861 |
| F statistic | 50 | 51 | 49 | 103 | 119 | 113 |
| Adjusted R-squared | 0.704 | 0.681 | 0.682 | 0.089 | 0.117 | 0.102 |

*Notes:* This table displays first stage OLS regression results. 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 Columns 1-3, and are robust to arbitrary heteroskedasticity in Columns 4-6.

# Appendix E Agency Variation

Federal procurement, in general, is no longer dominated by the acquisition of military products and services, as shown in Figure 1. R&D contracts have undergone a similar trend toward demilitarization, as shown in Figure E3. Only 44% of all R&D contracts awarded in 2015 were for "national defense R&D services" or "other defense R&D."[83]

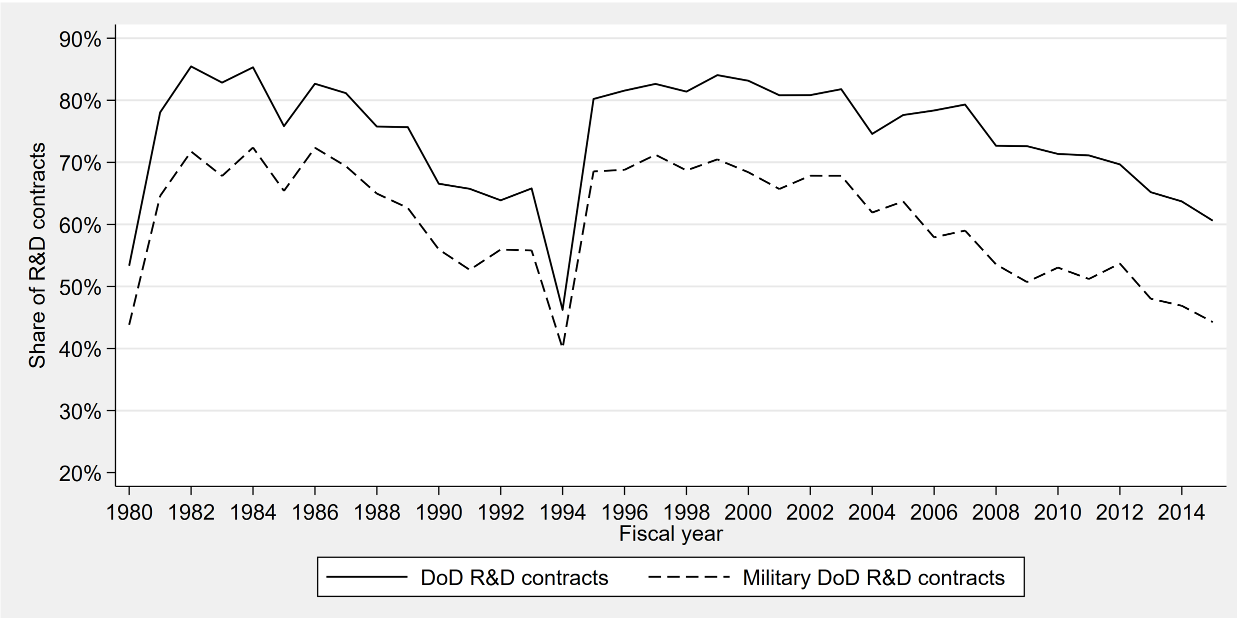



Figure E3: Share of DoD R&D and Military DoD R&D Contracts in All R&D Contracts Over Time
This figure plots the shares represented by DoD R&D contract dollars (solid line) and military DoD R&D contract dollars (dotted line), respectively, in all R&D contracts obligated by federal agencies to all recipients (not limited to our sample firms) over time.

Federal agencies are heterogeneous in the size and composition of their procurement contracts, as can be seen in Table E8, as well as the characteristics of their contractors, as can be seen in Table E2. Tables E3 and E4 further show that the dollar values of R&D contracts from DoD, NASA, and DoT are positively correlated (p-value $<0.001$). Defense R&D contractors tend to also work for NASA, as shown in Table E5. In general, if a firm is an R&D contractor for a non-DoD agency, it is also a DoD R&D contractor.

[83] The large dip observed in 1994 represents the combination of (i) R&D contracts from non-DoD agencies increasing in 1994 compared to 1993 and 1995 and (ii) DoD R&D contracts decreasing in 1994 compared to 1993 and 1995.

Table E8: 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) | 4,360,407 | 1.1 | 56.3 | 0.0 | 0.0 | 0.5 |
| R&D contracts ($ mm) | 152,334 | 4.8 | 134.8 | 0.1 | 0.3 | 4.2 |
| Non-R&D contracts ($ mm) | 4,030,148 | 1.0 | 52.2 | 0.0 | 0.0 | 0.4 |
| Noncompetitive non-R&D contracts ($ mm) | 1,255,908 | 2.0 | 78.7 | 0.0 | 0.1 | 0.9 |
| NASA | | | | | | |
| All contracts ($ mm) | 75,288 | 3.9 | 143.1 | 0.0 | 0.1 | 1.2 |
| R&D contracts ($ mm) | 19,064 | 7.3 | 193.3 | 0.0 | 0.3 | 3.9 |
| Non-R&D contracts ($ mm) | 49,477 | 3.2 | 129.4 | 0.0 | 0.1 | 0.7 |
| Noncompetitive non-R&D contracts ($ mm) | 14,736 | 5.3 | 218.3 | 0.0 | 0.0 | 0.5 |
| DoT | | | | | | |
| All contracts ($ mm) | 25,116 | 1.6 | 26.7 | 0.0 | 0.1 | 1.1 |
| R&D contracts ($ mm) | 1,983 | 3.9 | 62.6 | 0.0 | 0.2 | 1.6 |
| Non-R&D contracts ($ mm) | 21,838 | 1.5 | 21.6 | 0.0 | 0.1 | 1.1 |
| Noncompetitive non-R&D contracts ($ mm) | 6,704 | 0.8 | 7.0 | 0.0 | 0.1 | 0.7 |
| HHS | | | | | | |
| All contracts ($ mm) | 112,828 | 0.8 | 23.7 | 0.0 | 0.0 | 0.2 |
| R&D contracts ($ mm) | 2,971 | 2.3 | 12.7 | 0.0 | 0.1 | 2.6 |
| Non-R&D contracts ($ mm) | 104,998 | 0.8 | 24.5 | 0.0 | 0.0 | 0.2 |
| Noncompetitive non-R&D contracts ($ mm) | 32,494 | 0.3 | 11.8 | 0.0 | 0.0 | 0.1 |
| DoE | | | | | | |
| All contracts ($ mm) | 16,950 | 18.8 | 883.1 | 0.0 | 0.0 | 1.2 |
| R&D contracts ($ mm) | 1,853 | 3.0 | 15.5 | 0.0 | 0.4 | 4.3 |
| Non-R&D contracts ($ mm) | 13,552 | 23.3 | 987.5 | 0.0 | 0.0 | 1.1 |
| Noncompetitive non-R&D contracts ($ mm) | 3,219 | 23.7 | 389.2 | 0.0 | 0.0 | 2.0 |
| DHS | | | | | | |
| All contracts ($ mm) | 56,828 | 0.9 | 20.4 | 0.0 | 0.0 | 0.4 |
| R&D contracts ($ mm) | 814 | 3.2 | 30.6 | 0.0 | 0.1 | 3.0 |
| Non-R&D contracts ($ mm) | 53,291 | 0.9 | 20.7 | 0.0 | 0.0 | 0.5 |
| Noncompetitive non-R&D contracts ($ mm) | 19,561 | 0.7 | 26.8 | 0.0 | 0.0 | 0.4 |
| DoC | | | | | | |
| All contracts ($ mm) | 40,189 | 0.4 | 9.3 | 0.0 | 0.0 | 0.3 |
| R&D contracts ($ mm) | 386 | 3.4 | 49.7 | 0.0 | 0.1 | 1.2 |
| Non-R&D contracts ($ mm) | 37,845 | 0.4 | 8.1 | 0.0 | 0.0 | 0.3 |
| Noncompetitive non-R&D contracts ($ mm) | 9,781 | 0.1 | 1.0 | 0.0 | 0.0 | 0.2 |
| Other | | | | | | |
| All contracts ($ mm) | 4,264,685 | 0.3 | 59.2 | 0.0 | 0.0 | 0.1 |
| R&D contracts ($ mm) | 34,483 | 4.9 | 144.8 | 0.0 | 0.2 | 2.9 |
| Non-R&D contracts ($ mm) | 3,987,521 | 0.3 | 59.7 | 0.0 | 0.0 | 0.1 |
| Noncompetitive non-R&D contracts ($ mm) | 897,730 | 0.3 | 37.2 | 0.0 | 0.0 | 0.0 |

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." *Non-R&D contracts* include both service contracts (PSC codes that start with letters "B" through "Z") and product contracts (PSC codes that start with digits "1" through "9") *Noncompetitive non-R&D 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 E9: R&D Contractor Descriptive Statistics by Awarding Agency

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | DoD | | NASA | | DoT | | HHS | |
| | 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 |
| Publications | 32 | 137 | 53 | 175 | 84 | 236 | 79 | 236 |
| Patents | 63 | 250 | 104 | 362 | 182 | 513 | 100 | 376 |
| All contracts ($ mm) | 288 | 2,080 | 739 | 3,389 | 1,521 | 4,874 | 810 | 3,737 |
| R&D contracts ($ mm) | 48 | 448 | 131 | 737 | 271 | 1,069 | 138 | 804 |
| Non-R&D contracts ($ mm) | 240 | 1,689 | 609 | 2,745 | 1,251 | 3,942 | 673 | 3,029 |
| Commercial contracts ($ mm) | 28 | 163 | 57 | 204 | 118 | 288 | 70 | 274 |
| Noncommercial contracts ($ mm) | 241 | 1,856 | 654 | 3,103 | 1,380 | 4,470 | 679 | 3,245 |
| All grants ($ mm) | 1 | 12 | 2 | 10 | 4 | 14 | 2 | 8 |
| Sales ($ mm) | 5,757 | 18,188 | 9,287 | 25,760 | 17,775 | 36,061 | 8,962 | 21,523 |
| R&D stock ($ mm) | 1,166 | 4,362 | 1,948 | 6,172 | 3,540 | 8,491 | 1,931 | 5,420 |

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.

Table E2: R&D Contractor Descriptive Statistics by Awarding Agency (Continued)

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | DoE | | DHS | | DoC | | Other | |
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| R&D expenditures ($ mm) | 651 | 1,571 | 746 | 1,624 | 643 | 1,244 | 451 | 1,255 |
| Publications | 73 | 184 | 82 | 242 | 104 | 275 | 54 | 183 |
| Patents | 120 | 247 | 188 | 532 | 193 | 553 | 98 | 320 |
| All contracts ($ mm) | 1,513 | 4,948 | 1,522 | 5,017 | 1,801 | 5,552 | 510 | 2,795 |
| R&D contracts ($ mm) | 280 | 1,090 | 254 | 1,088 | 316 | 1,202 | 85 | 603 |
| Non-R&D contracts ($ mm) | 1,232 | 3,994 | 1,268 | 4,061 | 1,485 | 4,504 | 425 | 2,268 |
| Commercial contracts ($ mm) | 114 | 304 | 130 | 355 | 126 | 314 | 53 | 225 |
| Noncommercial contracts ($ mm) | 1,500 | 4,764 | 1,315 | 4,391 | 1,561 | 4,983 | 430 | 2,498 |
| All grants ($ mm) | 6 | 32 | 3 | 13 | 4 | 13 | 2 | 15 |
| Sales ($ mm) | 16,516 | 34,578 | 18,649 | 37,217 | 13,362 | 24,683 | 10,874 | 30,100 |
| R&D stock ($ mm) | 2,975 | 7,969 | 3,198 | 7,870 | 2,854 | 6,022 | 1,900 | 5,903 |

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.

Table E3: 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 |

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

Table E4: 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 |

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 E5: R&D Contractors by Awarding Agency

| Awarding agency | R&D contractors | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|---|
| (1) DoD | 781 | 781 (100%) | 218 (28%) | 93 (12%) | 108 (14%) | 80 (10%) | 80 (10%) | 67 (9%) | 249 (32%) |
| (2) NASA | 248 | 218 (88%) | 248 (100%) | 65 (26%) | 55 (22%) | 59 (24%) | 52 (21%) | 45 (18%) | 119 (48%) |
| (3) DoT | 101 | 92 (91%) | 65 (64%) | 101 (100%) | 36 (36%) | 38 (38%) | 39 (39%) | 31 (31%) | 69 (68%) |
| (4) HHS | 207 | 108 (52%) | 59 (29%) | 39 (19%) | 207 (100%) | 31 (15%) | 47 (23%) | 34 (16%) | 113 (55%) |
| (5) DoE | 95 | 80 (84%) | 59 (62%) | 38 (40%) | 31 (33%) | 95 (100%) | 25 (26%) | 25 (26%) | 67 (71%) |
| (6) DHS | 92 | 80 (87%) | 52 (57%) | 39 (42%) | 47 (51%) | 25 (27%) | 92 (100%) | 26 (28%) | 67 (73%) |
| (7) DoC | 72 | 67 (93%) | 45 (63%) | 31 (43%) | 34 (47%) | 25 (35%) | 26 (36%) | 72 (100%) | 55 (76%) |
| (8) Other | 372 | 249 (67%) | 119 (32%) | 69 (19%) | 113 (30%) | 67 (18%) | 67 (18%) | 55 (15%) | 372 (100%) |

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

## Appendix F Industry Variation

Our sample is drawn from a wide distribution of industries, as can be seen in Table F6. The classification scheme used to group sample firms into several main industries is presented in Table F7. Table F8 presents descriptive statistics by main industry. Table F9 presents mean comparison tests between R&D contractors other firms within the same main industry. Figure F4 shows changes in the share of all contracts (by value) awarded for R&D contracts and commercial contracts, respectively, by main industry.

Table F6: 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 | | |

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

Table F7: 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). |

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

Table F8: 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 |

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 F9: 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 |

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.

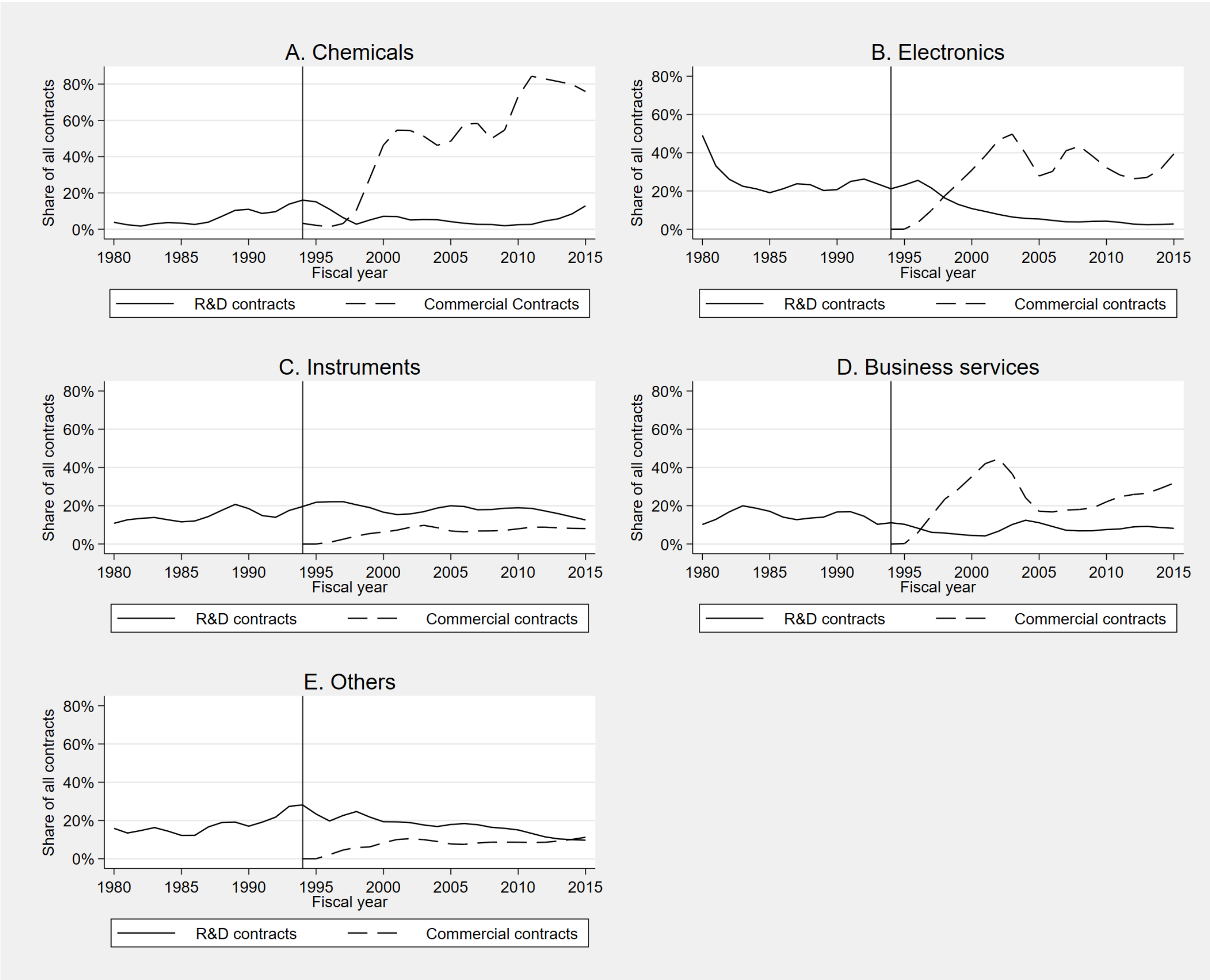



Figure F4: Trends in the Composition of Contracts by Main Industry
This figure presents the trend in the share of R&D contracts in all the contracts obligated by federal agencies to sample firms by main industry (solid lines). It also presents the trend in the share of commercial contracts in all contracts (dashed lines). The vertical lines mark the passage of the Federal Acquisition Streamlining Act of 1994.

Table F10 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 = 0.103).

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.

Table F10: Variation by Main Industry

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | ln(Publications) | | ln(Patents) | |
| | OLS | IV: Ind. R&D funding | OLS | 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 DoD may impose 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 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. 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 | 0.352 | 0.333 | 0.327 | 0.327 | 0.328 | 0.328 | 0.327 | 0.327 |
| | (0.017) | (0.023) | (0.019) | (0.018) | (0.018) | (0.018) | (0.018) | (0.018) | (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.

## 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 | 0.126 | 0.119 | 0.114 | 0.114 | 0.114 | 0.114 | 0.114 | 0.114 |
| | (0.010) | (0.013) | (0.011) | (0.010) | (0.010) | (0.011) | (0.010) | (0.010) | (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.

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<br>(0.025) | | | | | | | | |
| ln(Other R&D contracts)$_{t-3}$ | | -0.289<br>(0.175) | | | | | | | |
| ln(Non-DoD R&D contracts)$_{t-3}$ | | | -0.126<br>(0.078) | | | | | | |
| ln(Non-NASA R&D contracts)$_{t-3}$ | | | | -0.043<br>(0.024) | | | | | |
| ln(Non-DoT R&D contracts)$_{t-3}$ | | | | | -0.040<br>(0.023) | | | | |
| ln(Non-HHS R&D contracts)$_{t-3}$ | | | | | | -0.043<br>(0.024) | | | |
| ln(Non-DoE R&D contracts)$_{t-3}$ | | | | | | | -0.041<br>(0.024) | | |
| ln(Non-DHS R&D contracts)$_{t-3}$ | | | | | | | | -0.041<br>(0.023) | |
| ln(Non-DoC R&D contracts)$_{t-3}$ | | | | | | | | | -0.040<br>(0.023) |
| ln(R&D stock)$_{t-3}$ | 0.242<br>(0.015) | 0.230<br>(0.017) | 0.237<br>(0.016) | 0.241<br>(0.015) | 0.241<br>(0.015) | 0.241<br>(0.015) | 0.241<br>(0.015) | 0.241<br>(0.015) | 0.241<br>(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.2 Other Funding Shocks

Another way to 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 to examine two alternative shocks. First, we use changes in procurement that were triggered by the terrorist attacks of 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. 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. 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*.[84]

Table G14: Alternative Procurement Shocks

| | (1) ln(R&D expenditures) | (2) ln(Publications) | (3) ln(R&D expenditures) | (4) ln(Publications) |
|---|---|---|---|---|
| | OLS | IV: Global War on Terrorism shock | OLS | IV: Financial Crisis shock |
| $\ln(\text{R\&D contracts})_{t-3}$ | | 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.

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

## 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 $<0.05$). We also present OLS and 2SLS estimations where we use an inverse hyperbolic sine transformation.[85] Consistent with previous results, Columns 3 and 6 in Table G15 show that R&D contracts have a positive effect on publications (p-value $= 0.055$), 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.

Table G15: Alternative Specifications

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Publications | Inv. hyperbolic sine(Publications) | | Patents | Inv. hyperbolic sine(Patents) | |
| | Poisson | OLS | IV: Ind. R&D funding | Poisson | OLS | IV: Ind. R&D funding |
| ln(R&D contracts)$_{t-3}$ | 0.007 | 0.013 | 0.041 | 0.011 | 0.012 | -0.045 |
| | (0.003) | (0.002) | (0.021) | (0.004) | (0.002) | (0.027) |
| ln(R&D stock)$_{t-3}$ | 0.506 | 0.152 | 0.134 | 0.458 | 0.290 | 0.277 |
| | (0.051) | (0.013) | (0.012) | (0.067) | (0.017) | (0.017) |
| 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) | | | 99.94 | | | 99.94 |
| Firms | 2,387 | 3,632 | 3,580 | 3,166 | 3,632 | 3,580 |
| Observations | 32,854 | 43,914 | 41,047 | 40,628 | 43,914 | 41,047 |
| Adjusted R-squared | | 0.862 | 0.014 | | 0.838 | 0.043 |

*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 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 procurement projects are common, the outlays may occur one, two, or more years after the original

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

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 are similar to 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) | | |
| | OLS: Finite distributed lags | One-year lags IV: Industry R&D funding | Two-year lags IV: Industry R&D funding | Four-year lags IV: Industry R&D funding | Five-year lags IV: Industry 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 the effect 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 0.039 (using the *Industry R&D funding* instrument) and 0.299 (using the *Cold War shock* instrument), respectively. When we use only contractor firms, the 2SLS coefficient estimate on *R&D contracts* is 0.030 and 0.423, 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).

## G.7 R&D Contracts and Downstream Procurement

In Table G18, we estimate the relationship between winning R&D contracts and future downstream contracts. The coefficient estimates in Columns 1 and 3 show that winning R&D contracts is positively associated with the value of future procurement contracts (p-values $<0.001$), while winning grants is not (Column 2). Columns 4 and 5 indicate that our results are robust to using different measures of future downstream procurement contracts.

## G.8 Controlling for Grants

The guaranteed demand mechanism should be distinct from a 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 G19 confirms that our results are not sensitive to

Table G17: Unrelated Research Areas

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | ln(Related publications) | | ln(Unrelated publications) | | ln(Related patents) | | ln(Unrelated patents) | |
| | OLS | IV: Industry R&D funding | OLS | IV: Industry R&D funding | OLS | IV: Industry R&D funding | OLS | IV: Industry R&D funding |
| ln(R&D contracts)$_{t-3}$ | 0.008 | 0.024 | 0.009 | 0.023 | -0.000 | 0.001 | 0.010 | -0.041 |
| | (0.003) | (0.013) | (0.002) | (0.018) | (0.001) | (0.003) | (0.002) | (0.023) |
| ln(R&D stock)$_{t-3}$ | 0.060 | 0.049 | 0.120 | 0.105 | 0.007 | 0.005 | 0.251 | 0.240 |
| | (0.010) | (0.009) | (0.011) | (0.010) | (0.005) | (0.004) | (0.015) | (0.015) |
| 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) | | 99.94 | | 99.94 | | 99.94 | | 99.94 |
| Firms | 3,632 | 3,580 | 3,632 | 3,580 | 3,632 | 3,580 | 3,632 | 3,580 |
| Observations | 43,914 | 41,047 | 43,914 | 41,047 | 43,914 | 41,047 | 43,900 | 41,033 |
| Adjusted R-squared | 0.593 | -0.006 | 0.866 | 0.019 | 0.309 | -0.001 | 0.847 | 0.043 |

*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.

Table G18: The Relationship Between R&D Contracts and Downstream Procurement

| | (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 |
| [Has R&D contracts = 1]$_{t-1}$ | 2.667 | | 2.664 | 0.956 | 0.307 |
| | (0.154) | | (0.154) | (0.145) | (0.085) |
| [Has grants = 1]$_{t-1}$ | | 0.266 | 0.159 | -0.335 | -0.169 |
| | | (0.165) | (0.149) | (0.206) | (0.185) |
| ln(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.

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 (p-value <0.1 in Column 4), but not on patents.[86] 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.

Table G19: 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.

## G.9 Trends by Industry and Firm Subsamples

Table G20 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.

[86] 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*.

Table G20: 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 | -0.017 | 0.225 | 0.552 | 0.596 |
| | (0.009) | (0.022) | (0.141) | (0.155) |
| Time trend x [Chemicals = 1] | 0.118 | -0.023 | | |
| | (0.113) | (0.126) | | |
| Time trend x [Instruments = 1] | 0.008 | 0.067 | | |
| | (0.033) | (0.029) | | |
| Time trend x [Business services = 1] | -0.027 | 0.008 | | |
| | (0.020) | (0.081) | | |
| Time trend x [Others = 1] | 0.007 | -0.034 | | |
| | (0.009) | (0.043) | | |
| ln(Publications stock)$_{t-1}$ | | | 0.537 | 0.642 |
| | | | (0.125) | (0.143) |
| Time trend × ln(Publications stock)$_{t-1}$ | | | -0.130 | -0.151 |
| | | | (0.037) | (0.039) |
| ln(R&D stock)$_{t-1}$ | -0.001 | -0.036 | 0.364 | 0.476 |
| | (0.008) | (0.019) | (0.080) | (0.091) |
| Sample years | 1980-2015 | 1995-2015 | 1980-2015 | 1980-2015 |
| Firm fixed effects | Yes | Yes | Yes | Yes |
| Firms | 2,129 | 1,711 | 3,105 | 2,533 |
| Observations | 22,528 | 15,335 | 41,288 | 36,698 |
| Adjusted R-squared | 0.007 | 0.000 | 0.735 | 0.634 |

*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.10 Trends by Decade

Table G21 presents the changing composition of government contracts allowing for nonlinear time effects.

Table G21: 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 | -0.034 | -0.160 | | 0.029 | |
| | (0.133) | (0.088) | | (0.018) | |
| Indicator for Decade = 2000s | 0.501 | -0.114 | 2.397 | 0.003 | 0.201 |
| | (0.180) | (0.130) | (0.105) | (0.020) | (0.023) |
| Indicator for Decade = 2010s | 0.508 | -0.410 | 3.192 | 0.008 | 0.426 |
| | (0.214) | (0.150) | (0.141) | (0.049) | (0.037) |
| ln(R&D stock)$_{t-1}$ | 0.480 | 0.137 | 0.479 | -0.000 | -0.036 |
| | (0.054) | (0.035) | (0.057) | (0.007) | (0.019) |
| Sample years | 1980-2015 | 1980-2015 | 1995-2015 | 1980-2015 | 1995-2015 |
| Firm fixed effects | Yes | Yes | Yes | Yes | Yes |
| Firms | 4,367 | 4,370 | 3,657 | 2,129 | 1,711 |
| Observations | 52,793 | 52,866 | 36,836 | 22,528 | 15,335 |
| Adjusted R-squared | 0.738 | 0.657 | 0.687 | 0.007 | 0.003 |

*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.