Space Race: Automation Innovation and Labor's Share*

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Abstract

Labor's share has declined across a broad range of industries in many economies around the world over the last 50 years. We examine the effects of one of the largest public investments in science of the 20$^{\text{th}}$ century to understand how automation innovation affects the labor share over the long term. The Space Race - launched in response to the Soviet Union's Sputnik Satellite in 1957 - represents a shock to local automation innovation, which occurred virtually independent of local labor market conditions. Our analysis of city-industry level Manufacturing Census and National Aeronautics and Space Administration (NASA) publications data from 1947 to 2012 reveals two main findings. First, labor share fell five years after local NASA innovation shocks occurred. Over the longer-term, as firms and workers adjusted, we find that labor share increased in response to NASA technology shocks. Our analysis sheds new light on the dynamics of the impact of automation technology on workers.

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1 Introduction

The long-run decline in labor's share of income in many counties and industries is now well documented. What remains subject to debate is the role that technological change - especially automation and computer technologies - has played in explaining these trends. Many commentators see capital-biased technological change as the key driver of these trends. However, economists have pointed out that adjustments by firms and workers to these new more productive technologies may mitigate their role in explaining the declining labor share trend (Autor (2015), Acegmolu and Restrepo (2018), Michaels and Graetz (2018), and Autor and Salomons (2018)). To see how new technologies have shaped labor's share over the longer term we study the impact of one of the largest public investments in automation science - the Space Race.

Two central challenges have previously limited researchers' progress on this question. Using production function residuals to identify non-neutral technological change from other factors is a tall order. Measurement problems arise because a production function with a given form of technological change must first be postulated before measure of technological progress can be obtained, and price changes can also manifest in commonly used revenue-based total factor productivity measures. In addition, estimating the long-term effect of innovation on labor share requires both long-term data and a source of variation in innovation not driven by local fundamentals.

By examining how labor share responded to innovations in space science, we are able to address both challenges. We propose that the rapid expansion in space research during and after the Space Race serves as exogenous variation in the location of knowledge production. Because research expanded at pre-determined NASA research locations in response to nation-wide concerns over the launch of Sputnik in 1957, NASA activity created a positive shock to research virtually independent of local economic conditions. Furthermore, detailed historical Manufacturing Census data allow innovation effects to be estimated over a time horizon possible in few other contexts. While the Space Race is often seen as a case study of how public investments in science can create "good jobs," no research to date has explored its effects on labor's share.

Space science in the late 1950s and 1960s was mission oriented, which focused on sending a man to the Moon. The objective was not to generate new consumer products, per se. The fact that it is hard to pinpoint key blockbuster products reflects this fact. Yet, NASA research did lead to a number of discoveries in telemetry, integrated circuits, cryogenics, and computer simulation that had real economic value. Even more important than the NASA-related discoveries themselves were the indirect effects. NASA-funded research provided an invaluable opportunity for a generation of scientists, engineers and managers to gain first hand experience with rapidly developing computer technology. Summing up the changes in products, processes and instrumentation, Scranton (2007, 123) concludes, "NASA projects added critical momentum and capability to nascent innovations, providing essential test-beds for them (and the funding for revision and redesign), and to explore projects where the complexity of NASA-posed problems galvanized cross-disciplinary amalgams of technique and materials, with implications for the industrial world outside."

To conduct our analysis we use newly digitized Manufacturing Census data at the MSA level from 1947 until 2002. We obtain primary data at the MSA-Industry level from the Manufacturing Censuses of 1947, 1954, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, and 2002. We combine these data with the universe of NASA publications from 1926 until today, geo-referenced to MSAs. NASA's technical report publication database represents a unique and highly detailed record of research and innovation conducted by NASA. Roland (1985) points out that before 1958 the precursor to NASA "published more than 16,000 technical reports which were sought after and exploited by aeronautical engineers [and scientists] throughout the U.S. and abroad." Many of these reports became classics in the field of aerodynamics and are still used and referenced many years later (Anderson 1974). Our paper is the first to systematically link the innovations contained in these reports to local labor market outcomes.

Our first set of main results show that the effect of NASA research on labor share are dynamic. The initial impact five years after the NASA research point to a negative effect of research on labor share. This outcome would be expected if before inputs or prices adjust, firms experience a capital-biased productivity shock from NASA research. This finding corresponds closely with other research in the literature.

Over the longer term we see quite different results. Our estimates indicate that after ten years the effect of a NASA research shock becomes positive. We consider the differences between the short- and long-term effects to be driven by input and price responses as firms adjusted to new technology made available as a result of the Space Race.

The main results are highly robust. We show they change little when we add controls for industry trends, state trends, defense research locations, and the location of skills. We also show the pre-NASA publication trends in labor share are not present and that non-publication NASA activities do not affect labor share.

We also employ a shift-share instrumental variables approach to address the possible concern that unobserved technology or skill trends could drive both labor share and where and when NASA research leading to automation took place. Our approach utilizes the fact that different regions specialized in different scientific areas in 1957 before the launch of Sputnik and NASA needs for different scientific areas changed over time depending on the nature of the mission and the technological challenge. Initial technological challenges required the development of computer programs to model a successful launch of manned space vehicles in preparation for a Moon landing. Much of this development came from the Boston area. Autonomous technologies were required as the missions shifted to unmanned exploration of Mars and the solar system. Expertise in these technological developments centered at the Jet Propulsion Lab in Pasadena, CA.

The Space Race was very much a race. U.S. officials believed that the Soviets intended to land on the Moon in 1967 to celebrate 50 years since the communist revolution. Thus, early resources flowed to and resulting research flowed from places where facilities and expertise were already in place at the start of the Space Race. We can see this very clearly Figure 1 - areas that had space research in 1958 had a much larger increase in NASA research activity from 1958 until today than those that did not. The consequences for labor's share can be seen in Figure 2. All cities experienced a decline in labor share after 1954, but the decline was steeper in 1958 Space Places and then increased dramatically in those places after 1997. The results of a regression analysis reveal a similar pattern - the automation innovation from NASA research initially decreased but then increased the labor share.

Our next set of analyses examines the heterogeneous effects of local NASA research. We find that the effects are much stronger in industries that are closely linked to NASA. We find stronger effects for the low-skilled labor share than for the high-skilled labor share in both the short and longer run. Importantly, the short-term displacement effect of automation research is largely driven by the low-skilled labor share.

One strand of research has emphasized the role of reallocation between firms or plants using technologies with different labor shares (Autor, Dorn, Katz, Patterson, and Van Reenen (2017) and Oberfield and Raval (2014)). Our results show little effect of this type of reallocation in response to NASA research. Instead, we find that firms that initially had a high labor share responded similarly to those with an initially lower labor share. We do, however, find striking results when we stratify between industries based on initial measures of technology. Here the effect of NASA research on labor share is largely concentrated in firms with a high capital-labor ratio, pay a high wage, or that conduct innovation.

We further examine how labor markets responded to NASA research. We find the largest response in employment and little effect on wages. Though these effects differ somewhat by skill.

Our paper is related to three literatures. First, there is a large body of work examining the local employment effects of productivity growth and innovation. Researchers have paid close attention to the endogeneity of local productivity growth as well as migration frictions. Hornbeck and Moretti (2018) find that when a city experiences productivity gains in manufacturing, there are substantial local increases in employment and average earnings. Kantor and Whalley (2014) find that research universities increase wages at other firms, but have little effect on employment. Recent work considers how non-neutral agglomeration shapes the demand for skills in cities, but does not estimate the impact of non-neutral technologies directly. For example, Baum-Snow, Pavan and Freedman (2018) show how non-neutral technologies are important for understanding increases in urban inequality. Our paper is the first to estimate the effect of non-neutral technology shocks on workers' outcomes directly.

Second, there is now a well developed literature on the effects of automation on labor markets. The literature to date has largely focused on contemporaneous effects. Acemoglu and Restrepo (2017) present evidence that the diffusion of robots has reduced employment and lowered wages in U.S. counties. Michaels and Graetz (2018) use cross-country data and find that robots enhance productivity and have little effect on employment growth. In contrast, we examine both the contemporaneous and longer-term effects. By showing that NASA space research increased employment and the labor share only over the longer term, we demonstrate that adjustments are central to workers' realizing gains from automation technology.

Finally, we contribute to the literature on rent sharing by demonstrating how publicly sponsored research can affect labor's share. Kline, Petkova, Williams and Zidar (2017) have recently shown that workers receive rents for working at innovative firms. How public spending on research affects workers rents is less known. We present some evidence in this direction.[1]

2 Historical Background

Space Race. The Space Race began with the launch of Sputnik on October 4, 1957. President Eisenhower was not surprised by Sputnik; he had been forewarned by information derived from U2 spy plane overflight photos, as well as signals and telemetry intercepts.[2]

[1]Two central parameters determine when localized public research can have a local effect: the spatial extent of knowledge spillovers; and whether public research crowds in or crowds out private research activity. On the first point, Kantor and Whalley (2014) find evidence consistent with local spillovers from science, though other evidence indicates that the benefits of co-location can attenuate over time (Kantor and Whalley 2019). On the second point, Moretti, Steinwender and Van Reenen (2016) find that defense R&D has crowded in private research spending, not crowded it out.

[2]Logson (1995, 329) summarizes a July 5, 1957, memo from Allen W. Dulles, Director of Central Intelligence, to Donald Quarles, Deputy Secretary of Defense,"By 1957, the Central Intelligence Agency was aware that the Soviet Union had an active ballistic missile program and was preparing to launch a satellite. But the exact date of the launch was still uncertain. This memorandum from Director of Central Intelligence Allen

Eisenhower initially played down the importance of Sputnik, but after the high profile failure of the U.S.'s initial satellite effort – Project Vanguard – on live TV on December 6, 1957, public fear grew (Divine 1993). It was clear to many how important missile, space, and satellite technology was to surviving a potential nuclear war with the Soviet Union.[3] It was this technological anxiety that fueled the Cold War.

This growing fear led to the formation of the National Aeronautics and Space Administration (NASA) in 1958 with a budget of $89 Million. NASA began by taking over the X-15 experimental rocket-powered aircraft from the National Advisory Committee for Aeronautics (NACA) and Project Vanguard from the Navel Research Laboratory (NRL), but soon envisioned launching a person into space through Project Mercury. On May 5, 1961, astronaut Alan Shepard completed three orbits of the Earth and became the first American in space aboard Freedom 7. Following this success President Kennedy announced on May 25, 1961: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth."

President Kennedy's commitment to send a manned crew to the Moon and returning them to Earth by the end of the decade required a massive investment in space technology. NASA's budget grew accordingly, from $744 million (or about 0.9% of all federal spending) in 1961 to a peak of $5.933 billion (4.4 % of the federal budget) in 1966. With the rapid escalation in public funds devoted to space exploration, the Space Race was very much a race. NASA's spending did decline after the landing on the Moon was successfully completed in 1969, but still accounted for 1.92% of federal spending in 1970. Subsequently, the level of spending fluctuated between 0.75% to 1% of the federal budget from 1975 until the end of the 20^{th} century.

Growth and Organization. The Space Race is the canonical example of mission-oriented research and development spending where the mission was to land astronauts on the

Dulles to Deputy Secretary of Defense Donald Quarles indicates that American intelligence knew a Soviet space launch was imminent, but, as of early July 1957, was still unsure of the exact date of the launch."

[3]Satellites allowed Cold War adversaries to see over the Iron Curtain and accurately assess the strength of their opponent's intercontinental ballistic missile (ICBM) arsenal. They also allowed the targeting of the precise locations where the ICBMs were located – crucial information in the event of nuclear war. In an era of very limited information, satellites provided a major advantage.

Moon and safely return them to Earth. The Space Act of 1958 gave NASA broad powers to develop, test, and operate space vehicles and to make contracts for its work with individuals, corporations, government agencies, and others (Rosholt 1966, 61). Early in its history NASA made the decision to contract out much of the R&D work to private contractors.[4] This emphasis is reflected in the growth in personnel. While in-house NASA employees grew from 10,200 in 1960 to a peak of 34,300 in 1965, employment by NASA contractors increased from 30,500 in 1960 to 376,700 in 1965 (Van Nimmen, Bruno, and Rosholt 1976, 106). This massive increase in NASA employment outside of NASA was concentrated in private sector contractors, which accounted for 81% of total NASA employment in 1965. Universities, on the other hand, accounted for 3.1 % of total NASA employment in 1965.

Space Race spending was highly concentrated in relatively few sectors and firms. According to an input-output table constructed for NASA expenditures for fiscal year 1967 (Orr and Jones 1969), the top five manufacturing sectors accounted for about half of NASA expenditures.[5] Similarly, relatively few firms served as primary NASA contractors. In 1965 the top 10 contractors alone received nearly 70% of the spending. Leading technology companies receiving NASA projects included: North American Aviation, Boeing, Grumman Aircraft Engineering, Douglas Aircraft, General Electric, McDonnell Aircraft, International Business Machines, and Radio Corporation of America (Van Nimmen, Bruno, and Rosholt 1976, 197).

Technology Impacts. What did NASA scientists discover? How did NASA spending affect productivity? From the beginning NASA officials recognized that the transfer of technology to commercial applications was vital in securing public support. They sought partnerships with universities and established information distribution centers where private sector firms could access information on their latest discoveries.

Despite the prominence of the Space Race as one of the largest ever public investments

[4]T. Keith Glennan, the first administrator of NASA, was an advocate for contracting out. He wrote of his early decisions in 1958: "First, having the conviction that our government operations were growing too large, I determined to avoid excessive additions to the Federal payroll. ... I was convinced that a major portion of our funds must be spent with industry, education and other institutions." (Hunley 1993, 5)

[5]The five of our SIC 3 digit industries with the largest share of NASA spending are: Aircraft and Parts (SIC=372), Electrical Equipment (SIC=361-366), Computer And Office Equipment (SIC=357), Industrial Inorganic Chemicals (SIC=281), and Instruments (including Professional and Scientific) for Measuring, Testing, Analyzing, and Controlling (SIC=381-387).

in innovation, pinpointing a blockbuster consumer product solely attributable to NASA spending is hard. Indeed, many space-associated consumer products were already developed and the Space Race simply diffused them more broadly (e.g., Tang (Scranton 2006, 122)). Yet, the Space Race did have broader impacts on technological change.

Robbins, Kelly and Elliot (1972) identified 109 major developments in a field's technology during the 1960s by interviewing 161 recognized technological leaders. For each breakthrough they classified NASA's role in the technology's development: (1) an entirely new technology - 6.3% of developments; (2) an incremental advance in a technology - 64.8 % of developments; and (3) a consolidation of existing knowledge about a technology - 23.3 % of developments. Their findings echo an earlier analysis that concluded that Space Race research largely sped up progress with existing technologies rather than developed entirely new ones (Denver Research Institute 1971).

The areas where Robbins, Kelly and Elliot (1972) identified entirely new technologies from NASA spending included: Cryogenics, Energy Conservation, Ceramics, Metals, Integrated Circuits, Gas Dynamics, Non-Destructive Testing, and Telemetry. Telemetry, Integrated Circuits, Cryogenics, and Simulation are the areas with the greatest fraction of development that would not have occurred without NASA contributions. A few examples include the development of powdered metallurgy techniques in the field of high temperature metals, the computer enhancement of radiographs, high frequency power transistors, and the simulation of lunar landings (Robbins, Kelly and Elliot 1972, 18-21).

While the direct economic effects of space research were of modest magnitude, many argued that the harder to estimate indirect effects that occurred over a much longer time horizon were substantially larger. These later studies focused on some technologies where NASA's contribution became clearer over time. For example, NASA played an important role in the development of integrated circuits, first launching them into space in 1962 (Mathematica 1976, p. 101), structural simulation software - Nastran - between 1965 and 1970 (Mathematica 1976, p. 119), and digital communications, including the use of error-correcting codes and data compression in processing digital signals for modern-day digital communication and data storage (Midwest Research Institute 1988). Mazlish (1965) draws the comparison between the indirect effects of space science and the development of the railroad.

Summing up the contributions of NASA spending, Scranton (1996) concludes, "Contrary to consumer expectations, virtually all these contributions have been indirect, as a Denver Research Institute (DRI) study explained in the early 1960s, and hence imperceptible to most observers." Scranton (1996, 129) notes, however, that many innovations were directly applicable to manufacturing: "on the manufacturing process front, we can note innovations such as chemical milling and high-energy forming . . . as well as electron-beam, thermal, numerical control, ultra-cold, and electrical discharge machining; electrolytic grinding; plasma and induced magnetic field welding; plus stretch, magnetic, and shear forming." On instrumentation: "The rise of reliable, precise, and speedy instrumentation as a key dimension of technical practice preceded NASA's inauguration, but its momentum accelerated at a rapid pace once piloted spaceflight became a national priority" (Scranton 1996, 136). On management practices: "NASA projects provided test platforms or incubators for a number of managerial techniques as well: project management and team-tasking, high-level quality control, reliability analyses, and handling concurrency/redesign challenges" (Scranton 1996, 137).

Others also noticed the staggering developments in computerization and automation. Describing NASA's Performance, Evaluation and Reporting Technique, Bilstein (1996, 286) notes that "PERT was a sophisticated and complex computerized system, with inputs beginning, literally, at the tool bench. Technicians on the floors of the contractor plants around the country monitored the progress of nearly all the hardware items and translated the work into computer cards and tapes. The PERT network was broken down into 800 major entities and summarized 90,000 key events taking place around the country."

A major improvement in quality control was the automated checkout procedure. As Bilstein (1996, 240) describes: "manual checkout techniques for the earliest S-IV stages; pre-checkout, acceptance firing, and post-checkout required a total of 1200 man hours per stage. Veteran 'switch flippers' who had for so long had been vital links in the loop ... were now replaced by ranks of grey-enameled computers . . . Although the magnitude of testing rose 40 percent per stage the new automated systems reduced checkout time to just 500 man hours total." Indeed, if the Space Race had a significant effect on the development of the leading general purpose technology – the digital computer – the effects may have taken some time to fully manifest and may have occurred outside of the space sector. Our analysis investigates this possibility directly.

3 Automation Innovation and Labor's Share

3.1 Conceptual Framework

We introduce a simple framework to understand how NASA innovation might affect the labor share. Building off of Acemoglu and Restrepo (2018) allow NASA innovation to increase the set of tasks that can be automated, which enhances productivity.

We consider aggregate output, Y, to be given by

$$Y = \frac{B}{1-\alpha} K^{1-\gamma_N S+\gamma_I S} L^{\gamma_N S-\gamma_I S} \tag{1}$$

where K is capital, L is labor, and α is share of intermediate goods in task production. We allow NASA innovation S to affect production technology in two ways. First, by setting $N = \gamma_N S$ we allow NASA innovation to increase the quality of output from a task - a measure of productivity in this context. Second, by setting $I^* = \gamma_I S$ we allow NASA innovation to increase the fraction of tasks that can be automated.[6]

Setting aggregate output to aggregate income we can express labor's share as:

$$s_l = \frac{wL}{Y} \tag{2}$$

[6] This is the Cobb-Douglas expression from Acemoglu and Resrepo (2018). It is a highly tractable expression of the more general model given in Corollary 1 under the assumptions that (i) labor is equally productive in all tasks where it has a comparative advantage over machines, (ii) the elasticity of substitution between tasks is one, and (iii) when the elasticity of substitution between task specific intermediates that embody the state of technology and labor is one. In future work we seek to relax these assumptions.

The firm's profit maximization problem is given by

$$\Pi = P_i y_i - rK - wN \tag{3}$$

subject to

$$y_i = P_i^{-\rho} Y. \tag{4}$$

The first order conditions with respect to capital are $P_i F_K = \mu r$ and with respect to labor are $P_i F_N = \mu w$. Firms set the marginal revenue product of factors as a markup $\mu = \frac{\rho}{\rho - 1}$ over factor prices.

$$\mu w = \frac{\partial Y}{\partial L} = \frac{B}{1-\alpha} K^{1-\gamma_N S + \gamma_I S} \gamma_N S - \gamma_I S L^{\gamma_N S - \gamma_I S - 1} \tag{5}$$

Substituting into the labor share expression we get

$$s_l = \Big(\frac{\gamma_N - \gamma_I}{\mu}\Big) S \tag{6}$$

so that

$$\frac{\partial s_l}{\partial S} = \frac{\gamma_N - \gamma_I}{\mu} \tag{7}$$

The first term $\gamma_N > 0$ is the *productivity effect* of public research that enhances the productivity of labor task production and, thus, increases labor share. The second term $\gamma_I > 0$ is the *displacement effect* of public research that increases the fraction of tasks possible to automate and thus reduces labor share.[7]

The sign of the effect NASA innovation has on labor's share depends crucially on which effect dominates. If the automation (i.e., displacement) effect is larger than the productivity effect, then NASA innovation will reduce labor's share. This outcome is the case featured in much of the policy discussion on the potential for automation to destroy jobs. The other case occurs when the productivity effect dominates the displacement effect. Here NASA

[7] Acemoglu and Restrepo (2017) also include a reallocation effect of automation technology that results in a third term in the automation labor share relationship. We do not address reallocation in the interests of keeping the model as simple and focused as possible.

innovation will create jobs. A number of economists have discussed this possibility with the example describing how automatic teller machines have not displaced millions of bank teller jobs, but resulted in bank tellers increasingly focused on client relationship tasks. Which effect dominates and over what time horizons is an empirical question.

3.2 Measurement Framework

To examine how space innovation affected labor share, we use the rapid growth in NASA research following Sputnik as a source of exogenous variation. We estimate the equation

$$LS_{ijt} = \beta_1 NASApublications_{i,t-5} + \beta_2 NASApublications_{i,t-10} + \theta_i + \delta_j + \gamma_t + \epsilon_{ijt}. \quad (8)$$

LS_{it} is the labor share in MSA i, industry j, in year t. γ_t is a set of year fixed effects (1947 serves as the reference year) that flexibly control for national time series trends in labor share, θ_i is a set of MSA fixed effects that absorb time-invariant characteristics across MSAs, and δ_j is a set of industry fixed effects that absorb time-invariant characteristics across industries. ϵ_{ijt} is random error.

The event-study specification we use describes the dynamics of the space research effects flexibly. Our parameters of interest are β_1 and β_2 that measure how labor share responds to NASA research 5 and 10 years later. If NASA research leads to the development and adoption of labor saving technology and the output elasticity is sufficiently low, then we may expect $\beta_1 < 0$ and $\beta_2 < 0$. Conversely, if NASA research leads to the development and adoption of neutral technology and the output elasticity is sufficiently high then we may expect $\beta_1 > 0$ and $\beta_2 > 0$.

Our empirical approach utilizes variation in research that is plausibly exogenous to local manufacturing. Because NASA research expanded dramatically following the launch of Sputnik in 1957 at pre-determined locations that already had space research infrastructure in place, such research activity created a positive shock to research virtually independent of local economic conditions. Our central identifying assumption is that changes in space research at NASA research centers were unrelated to changes in unobserved determinants of local manufacturing. While it is not possible to test our identification assumption directly, estimates of β_t and β_{t-5} and examining the agricultural sector allow us to test for "effects" where none is expected.

A few other estimation details are worth noting. Our analysis is based on an unbalanced panel of industry-MSA units that reported manufacturing activity in 1958. In all specifications, to address the possibility of persistent autocorrelation in outcomes within a local area and across industries, we employ two-way clustered standard errors at the MSA and industry level.

4 Data and Descriptive Statistics

NASA Data. We harvest the meta data for the universe of publications on the NASA Technical Reports Server (NTRS) (https://ntrs.nasa.gov/search.jsp). The NTRS provides scientific and technical information (STI) created or funded by NASA and contains information and sometimes original documents related to aerospace science. Documents in the NTRS range from conference papers, journal articles, meeting papers, patents, research reports, images, movies, to technical videos. Our central fields of interest are scientist names, locations, and technological keywords. The data cover publications from 1926 until today. From this database we use all of the publications with scientist names and locations for at least one author. We then geo-reference the reported city locations for the first 10 authors on an item to counties, which are ultimately linked to MSAs.[8]

Manufacturing Data. The primary data we use to estimate the labor share impact of NASA research are from the Manufacturing Census. We obtain data at the MSA-Industry level from the Censuses of 1947, 1954, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, and 2002. We obtain data on total value added, total employment, total annual wages, and total plant and equipment additions for each MSA-Industry cell. Our main measure of labor share is defined as the ratio of total payroll to value added in the industry-MSA cell. We take SIC 3 digit industries (1972 definition) in the MSA as the unit of analysis. Because not

[8]Many publications with more than 10 authors list those after the first 10 as "et al.", and so those that do report more authors are not representative. Relatively few publications have 10 or more authors.

every 3 digit industry reports in every census, we aggregate those that do not, leaving us with 54 possible typical and synthetic 3 digit SIC industries.

Additional Data. We also utilize data to control for local skill levels and defense research spending. To control for MSA-level skill level we obtain data on college graduates from the Population Census, from the *College Blue Books* we obtain data on university enrollment, and from the 1962 Roster of Scientific Personnel we construct research scientists per capita by location. We obtain MSA-level defense spending controls with the fraction of scientists receiving defense grants reported in the 1962 Roster of Scientific Personnel, and total defense contract spending in 1960 from Isard and Ganschow (1961).

Sample Selection and Descriptive Statistics. We select our sample of MSAs and industries to capture major urban labor markets that we observe for multiple periods. We next merge the scientist roster data with NASA publications data. To do so we first aggregate the NASA fractional publications - adjusted for the number of coauthors - to the MSA level. We construct annual totals of the total publications in each year since the data begin in 1926. For example, one cell in our data in 1958 would be the total NASA publications in Boston in 1958. As labor share is our main variable of interest and can be subject to measurement error, we trim the sample of extreme values. Specifically, we drop observations that are below the 1st percentile of value added labor share (0.14) or above the 99th percentile of value added labor share (0.93). Another issue is that the minimum numbers of employees required for an industry-MSA cell to report changes over time. We apply the same minimum number across all years to enhance comparability. A further issue is that not all industry-MSA cells report each census. To be included in our panel, we require that an industry-MSA cell must be reported in the 1958 Manufacturing Census. We are left with a panel containing 10,557 MSA-Industry level observations.

Table 1 provides a first look at summary statistics of relevant measures in 1958, the full year following Sputnik's launch in October 1957. The first column reports summary statistics for the full sample in 1958. We then divide cities into space places where NASA-relevant research had not been conducted by 1958 (column 2) and other cities that had any NASA-relevant research before 1958 (column 3). The forth column of Table 1 displays t-statistics for the test of differences in each variable according to 1958 NASA research status.

In panel A we see that both the labor share and capital-labor ratio were remarkably similar across cities with different initial NASA research activity. Cities that initially had NASA research had larger wage bills, valued added, and employment, however. They also paid higher annual salaries.

In panel B we see that cities that initially had NASA research had higher patenting and a greater percentage of scientists having received defense funding, but similar levels of overall defense contract spending. Finally, we compare skill measures in panel C. Here we see little difference in the share of non-production workers in the manufacturing firms we use for our main analysis. There are, however, differences in a broader measure of population skill levels - percentage college graduates. Little difference is present for university enrollment per capita. The important differences we detect in the table highlight the value of our fixed effects estimation strategy.

5 Results

Main Results. We present the main results in Table 2. Column (1) displays our estimates of 5-year and 10-year lag effects of local Space Race research on labor share. The results demonstrate that NASA publications reduced the labor share after 5 years. However, with a 10 year lag NASA publications increase labor share. These results are consistent with short-term labor saving technological change. They are also consistent with a medium run response of increased output, reduced output prices, without a substantial change in wages. In column (2) we see similar, though slightly larger, results when we add industry controls.

The magnitudes appear economically significant. The results in Column (2) indicate that a one standard deviation increase in NASA publications in an MSA (1.64, measured in hundreds) increased labor share by over one-half percentage point (0.57) ten years later. By comparison, Karabarbounis and Neiman (2014) find that labor share has fallen by 5 percentage points over the last 35 years.

Dynamics and Falsification. In Table 3 we first examine whether there are prior trends in labor share before NASA publications change and conduct a falsification exercise. One concern thus far could be that local NASA publications may be determined by local labor market outcomes. For example, NASA could expand research where companies are already using advanced labor saving technology or where skilled labor is available at relatively lower cost.

We address this concern in two ways. First, we test for effects of future NASA research on contemporary labor market outcomes. Our approach is to include NASA publications 5 years in the future and in the current year as control variables. We report the results in Table 3 columns (1) and (2). These results reveal little evidence that local trends in NASA publications are driven by trends in local labor share. While this finding may be unsurprising as NASA research typically expanded where very specific research infrastructure was already in place, the validation of our design is worthwhile.

In a similar vein we examine whether other NASA output that did not generate discoveries – for example, non-peer reviewed technical reports or public presentations – also have impacts on labor's share. In column (3) and (4) of Table 3 we find little evidence of statistically significant effects of other NASA output on labor's share in manufacturing. The results in Table 3 strengthen the validity of our research design.

Instrumental Variables. In Table 4 we use persistence in local research specialization to tackle the identification challenge directly. We use a shift-share instrument where the share is the local share of a given topic area of research and the shift is the national trend of research in that scientific topic. The idea is that the initial scientific specialization of an area is exogenous to future trends in local labor share, and when more research is demanded in a particular scientific field it expands research in those areas that have already specialized in it. For example, Los Angeles County, where the Jet Propulsion Laboratory is located, is specialized in Physics, Communications, and General technologies; therefore, to the extent that NASA demanded these technologies, Los Angeles research would be stimulated as a result of the Space Race. In contrast, Cleveland, where Glenn Research Center is located, is specialized in Propulsion Systems, Materials Processing, and General technologies. Thus, Cleveland's NASA research activity was particularly exposed to fluctuations in NASA demand for these technologies.

In column (1) and (2) of Table 4 we see that our IV results are very similar to the main results in Table 2 column (2) when we use the lag of the location publication share to construct the IV. We obtain very similar results when we use the 1958 share of publications to create the instrument in columns (3) and (4). Indeed, the point estimates and patterns of statistical significance are almost identical to those above in Table 2. Our IV strategy further supports the validity of our main approach above.

Robustness We next examine the robustness of our results to the inclusion of additional control variables in Table 5. We first consider the possibility that NASA publication effects are confounded with local defense research. Defense research spending is not available at the local level in all years in our sample. Our strategy uses initial year local defense research indicators interacted with year fixed effects to allow those cities to follow a flexible time trend depending on defense research intensity. We see in columns (1) and (2) of Table 5 that controlling for either 1960 defense spending per capita interacted with year fixed effects or percentage of scientists receiving defense research funding interacted with years does little to change our main results. Differences in technology across areas could explain changes in labor share. We control for 1961 IBM mainframes per capital times year fixed effects in column (3). Across all of these specifications the results change little.

An important confounder is skill - as labor markets with different levels of skill are known to follow different trends for a variety of labor market outcomes. We again address this possibility in a variety of ways. In column (4) we show that adding time trends that differ by the MSA percentage of college graduates in 1960 does little to alter the results. We also show that controlling for the contemporaneous percentage of college educated population does little to change in the main results in column (5). In column (6) we look at the flow of new highly skilled workers from university enrollment in 1960 times year fixed effects. Finally, we look to whether our results are sensitive to controlling for trends in upper tail human capital - where technology may be adopted regardless of NASA activity. Our results change little across these specifications (see column 7).

Another possibility is that firms co-located with NASA publications would have experienced different trends in labor share than those not co-located. To address this concern with allow each industry or each state to follow its own non-linear time trend. Adding industry or state times year fixed effects in columns (8) and (9) of Table 5, respectively, does little to change our results. This last set of controls do little to alter the point estimates, but they are less precise.

Heterogeneous Effects. We next turn to heterogeneous effects. In Table 6 we examine whether the impacts of NASA automation differ by skill. Here we see that the initial effects are much stronger for low skill labor share. That low skilled workers may experience a particularly large displacement effect is consistent with the task-based theory that low complexity tasks are automated first. Interestingly, the longer term positive new task effect is similar across skill groups.

In Table 7 we look at how the effects differ by initial characteristics. In columns (1) and (2) we see that the NASA effects are concentrated among those firms that pay higher salaries. Similarly in columns (3) and (4) we see that the point estimates are larger in firms that are more innovation intensive. These results are consistent with the displacement and task creation effects being concentrated in non-routine innovation intensive tasks that pay more.

Prominent explanations for how the aggregate labor share can decline in response to new technology, even when many estimates indicate the elasticity of substitution between labor and capital is less than one, feature reallocation. The key idea is that a wave of new technology can reallocate labor from high labor share firms towards those with lower labor shares.

In Table 7 columns (5) and (6) we investigate the role of reallocation here by stratifying our sample by initial labor shares or capital labor ratio in an MSA-industry cell in 1958. If reallocation is an important channel we should see that those high labor share firms should grow faster in employment that those with low labor shares. Similarly, if lagging firms have lower capital labor ratios, we would see larger effects here. In Table 7 we see the effects of NASA publications are larger when the labor share is high or the capital per worker is high. This provides only mixed support for a reallocation effect.

A last set of heterogeneous effects we examine are industry linkages with NASA. The dynamics of the results thus far may reflect the dynamics of the diffusion rather than the impact of the technology. A new technology may first reduce labor share in the same city as the NASA research and then diffuse to other cities and reduce labor share there. Thus, a lag in the diffusion of technology from space cities to other control cities could explain the dynamics.

We test for this possibility that diffusion can explain our results by looking at the effects within industries that are closely connected to NASA. These industries would be expected to experience fast diffusion so are likely aware of the technological developments in the short term and the longer term. In Table 8 we see that the effects are larger in industries more closely connected to NASA. We also see that the effect dynamics - an initial negative and longer term positive effect - are consistent with our main estimates. It seems that dynamics of technology impact - not the dynamics of technology diffusion - explain our results.

Technology Types. We next examine whether the effects depend on the nature of the technology in the NASA innovation. To do so we classify each NASA publication into the 6 NBER patent technology categories.[9]

In Table 9 we examine whether certain technology classifications have particularly large effects. These technology categories are relatively aggregated. We may expect that automation innovation is primarily concentrated in the Computers and Communications, and Electrical and Electronics categories in columns (2) and (4) of Table 9. In this sense the fact that these columns show significant effects supports our results. However, most other

[9]To classify technology this way we create a cross walk between NASA technology keywords and NBER patent classification 1 digit codes. We link the patents in the NASA publication data to the NBER patent data to build this crosswalk.

columns show significant results also. This is likely due to automation technologies being present in each aggregate category. For example, motors, engines and parts, and optics are components of the Mechanical category in column (5). We see the effects of NASA innovation are very similar across technologies suggesting that automation innovation occurred within each technology category rather than in only a few.

Labor Markets. Which labor market component drive our main results? In Table 10 we first decompose the wage bill effect into two components - employment level and the price of labor. In columns (1) and (2) we see that the employment effects are substantially larger than the wage effects - suggesting that the supply of labor is relatively elastic. We also examine how the capital labor ratio responded in column (3). Here we see that the capital labor ratio falls in the longer term - consistent with a drop in the labor share.

Innovation and Markups. How does local private sector innovation respond to NASA innovation? There are two possibilities. On the one hand, NASA innovation may be an important input into private sector innovation that builds off the basic research findings from NASA. On the other, NASA innovation may crowd out private innovation. A lagged innovation effect could possibly explain the labor share dynamics we see. Similarly, NASA innovation may affect local markups. These will also be related to labor share and could change our interpretation of the labor share effect. To estimate markups we use the first order conditions approach developed in De Loecker and Warzynski (2012) using a second order translog production function. However, we allow for the non-neutral nature of NASA innovation by including the lag of NASA Publications in a city as an additional state variable - treating it similarly to the capital stock when the firm makes decisions about adjusting the variable input - labor - to the state of productivity.[10]

In table 11 we find little effect of NASA innovation on patents whether weighted by citations or not in columns (1) and (2). Thus there seem to be little follow on innovation or crowd out from NASA innovation. In column (3) we see little effect of NASA innovation on

[10] This approach is not typically used to estimate non-neutral productivity. We thus do not focus on neutral technology efficiency measure produced by this estimation approach as an informative outcome in our setting.

markups. This implies that cost reductions from enhanced efficiency from NASA innovation are passed on to consumers - consistent with the aggregate evidence on the industry level relative prices. We find little effect of NASA publications on these outcomes.

6 Conclusions

Labor's share has declined across a broad range of industries in many economies around the world over the last 50 years. What role does publicly sponsored innovation play in driving these trends? We study the effects of one of the largest public investments in science of the 20$^{\text{th}}$ century to see how innovation matters. We propose the Space Race - launched in response to the Soviet Union's Sputnik Satellite in 1957 - as a shock to public research virtually independent of local labor market factors. Our analysis of city-industry level Manufacturing Census and National Aeronautics and Space Administration (NASA) data from 1947 to 2002 reveals that local Space Race research increased labor share 10 years later. This increase in labor's share can be interpreted through a model with relatively elastic final goods demand and inelastic labor supply.

Our analysis of local labor markets indicates that innovation is positively related to labor share over the longer term. Limitations of our analysis suggest important avenues for further work. Our results suggest that the slowdown in productivity growth in the mid 1970s may be related to the decline in the labor share. As we focus on local labor markets our estimates are less informative for aggregate tends. Future work should consider aggregate implications.

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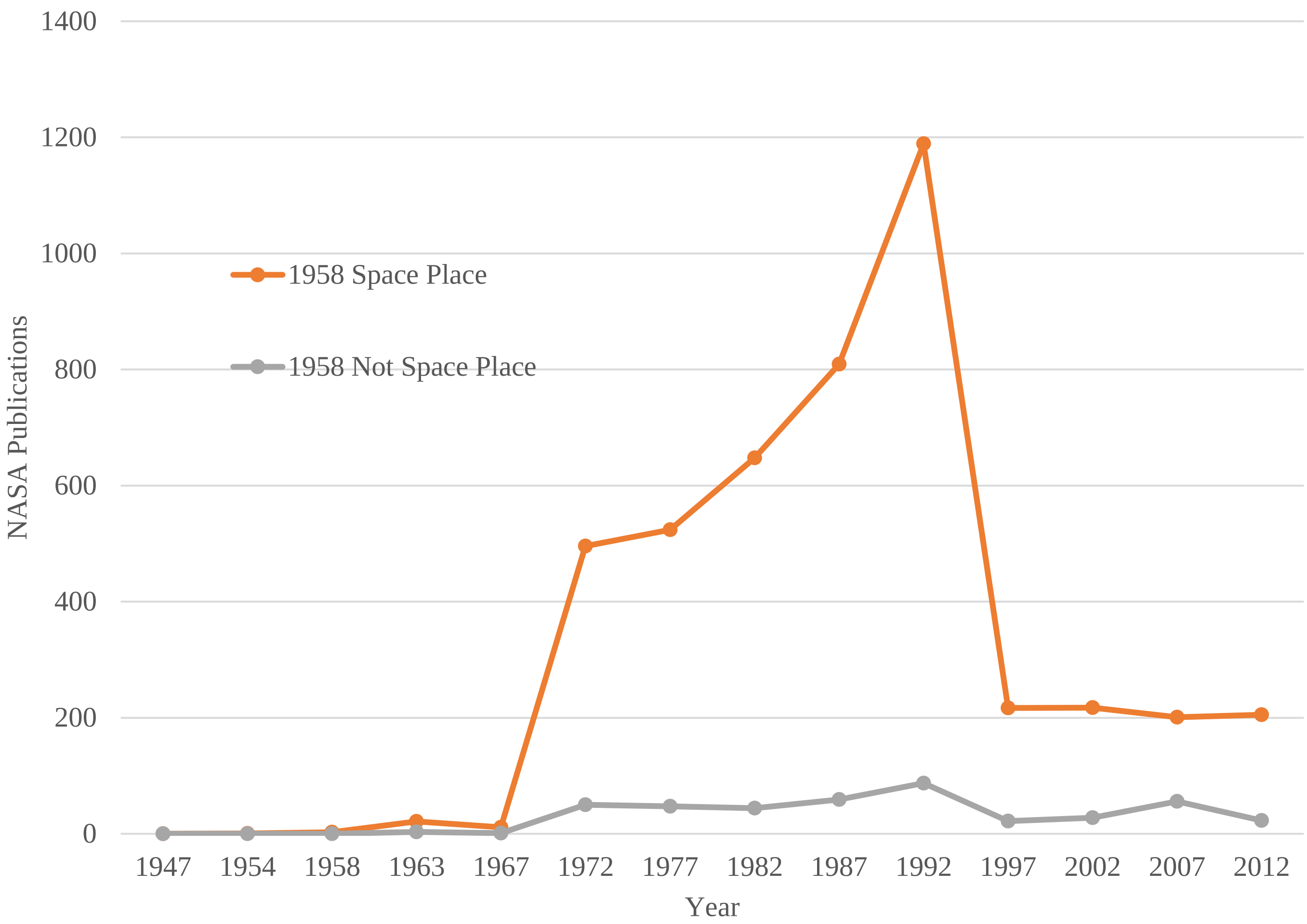
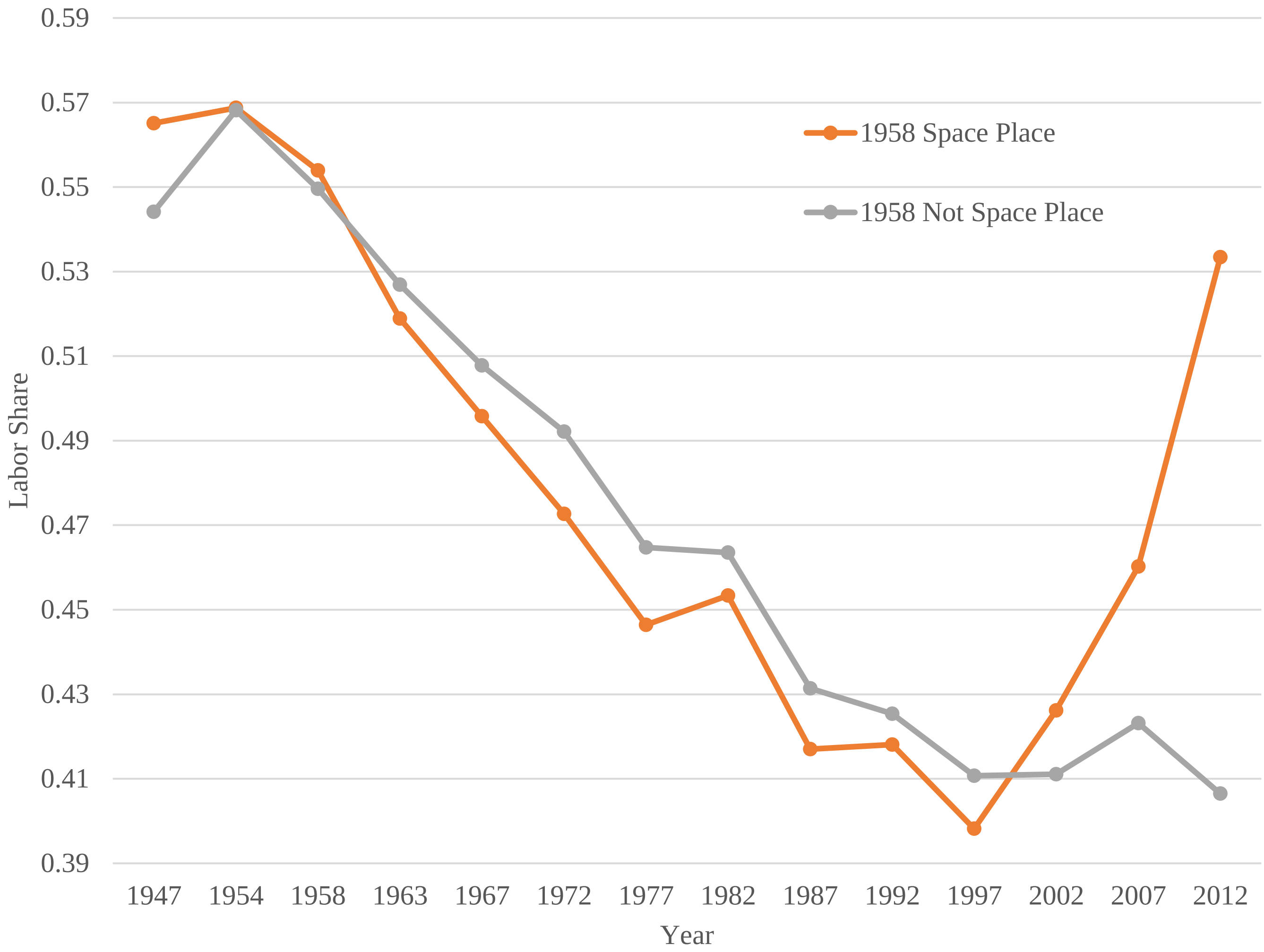
Figure 1: NASA Publication By Presence of NASA Research in 1958



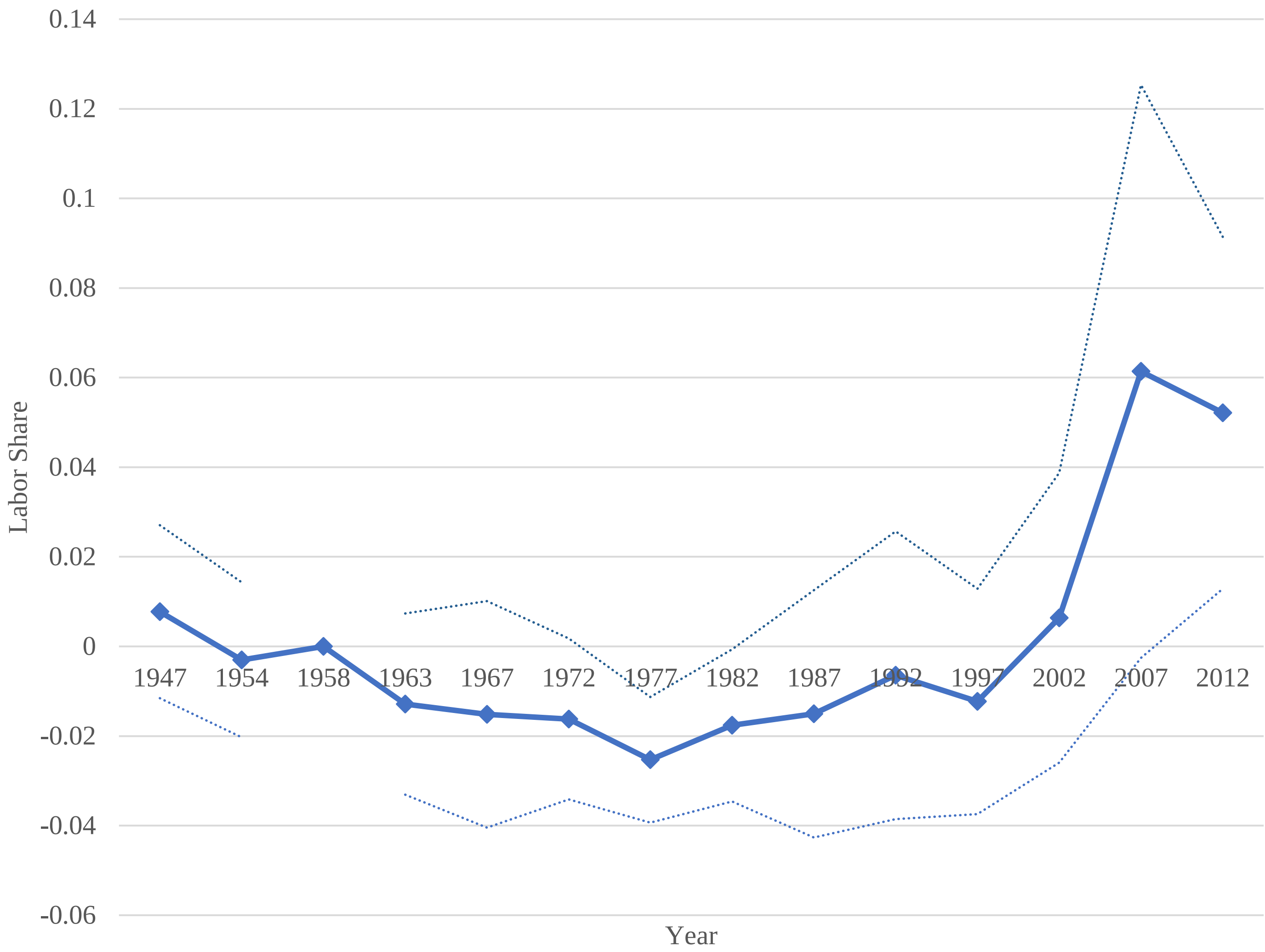
Notes: Source Author's calculations using data on NASA publications from 1947 to 2012. The orange line depicts the number of NASA publications in each manufacturing census year in cities that had NASA research in 1958. The grey line depicts the level of NASA publications in each manufacturing census year in places that did not have NASA research in 1958.

Figure 2: Labor Share By Presence of NASA Research in 1958



Notes: Source Author's calculations using data on NASA publications from 1947 to 2012. The orange line depicts the labor share in each manufacturing census year in cities that had NASA research in 1958. The grey line depicts the labor share in each manufacturing census year in places that did not have NASA research in 1958.

Figure 3: Labor's Share Space Place Differential Trends



Notes: Source Author's calculations. The solid line depicts the year times 1958 space place interactions from a regression with labor share as the outcome, including msa and year fixed effects. The dashed blue lines depict 95% confidence intervals for the year times 1958 space place interaction estimates.

Table 1: Descriptive Statistics, 1958

Sample=	Full	Any NASA Publication before 1958		t-test for (2) –(3) difference
		No	Yes	
	(1)	(2)	(3)	(4)
Panel A: Manufacturing Firm Outcomes				
Labor Share	0.55	0.55	0.55	0.46
	(0.13)	(0.14)	(0.12)	[0.64]
Capital-Labor Ratio	5.75	5.81	5.72	-0.18
	(8.04)	(8.34)	(7.77)	[0.86]
Wagebill	24,256	12,506	34,503	2.94
	(63,692)	(23,245)	(83,469)	[0.01]
Value Added	45,199	24,145	63,559	2.87
	(113,934)	(46,403)	(147,361)	[0.01]
Annual Wage	7,838	6,976	8,589	3.34
	(5,732)	(4,649)	(6,442)	[0.00]
Employment	4,257	2,516	5,775	2.84
	(7,356)	(3,854)	(9,136)	[0.01]
Panel B: Local Innovation and Defense Spending				
Patents	5	2	8	2.66
	(19)	(8)	(24)	[0.01]
Citation Weighted Patents	24	9	38	3.06
	(78)	(30)	(100)	[0.00]
Defense Contractor Spending (1960) Per Capita	0.24	0.28	0.21	0.54
	(0.54)	(0.76)	(0.18)	[0.59]
Percent Scientists with Defense Funding (1962)	0.12	0.08	0.15	2.74
	(0.10)	(0.08)	(0.11)	[0.01]
Panel C: Local Skill				
Non-Production Workers Employment Share	0.28	0.28	0.28	0.83
	(0.12)	(0.13)	(0.11)	[0.41]
College Graduate Percentage (1960)	0.09	0.08	0.10	2.38
	(0.03)	(0.02)	(0.03)	[0.02]
University Enrollment Per Capita	0.01	0.01	0.01	1.57
	(0.01)	(0.01)	(0.01)	[0.12]
n	1,258	586	672	

Notes: Sources Manufacturing Census, NASA publication, Population Census, Roster of Scientific Personnel, United States Trademark and Patent Office, and Blue Book data. The unit of observation for MSA-Industry for the year 1958, unless indicated. The first column reports the mean of the indicated variable with the standard deviation in parentheses for the full sample. The second column reports the mean of the indicated variable with the standard deviation in parentheses for the sample of MSA's without NASA publications before 1958. The third column reports the mean of the indicated variable with the standard deviation in parentheses for the sample of MSA's with a NASA publication before or in 1958. The forth column reports the results of a t-test between columns (2) and (3) with the standard errors clustered at the MSA level.

Table 2: NASA Publications and Labor's Share

Dependent Variable:	Labor's Share$_{it}$ * 100	
	(1)	(2)
NASA Publications$_{i.t-5}$	-0.31**	-0.28**
	(0.10)	(0.11)
NASA Publications$_{i.t-10}$	0.35***	0.46***
	(0.12)	(0.11)
Controls:		
MSA Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Industry Fixed Effects	No	Yes
R^2	0.18	0.52
Observations	11,363	11,363

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). The main entries are coefficient estimates with standard errors clustered at the MSA and industry level in parentheses. NASA publications$_{i,t-10}$ are the NASA publication in the MSA lagged 10 years (2 manufacturing censuses) in hundreds of publications.

Table 3: NASA Publications and Labor's Share – Dynamics and Falsification

Dependent Variable:	Labor's Share$_{it}$ * 100			
	(1)	(2)	(3)	(4)
NASA Publications$_{i.t+5}$	-0.08	-0.07		
	(0.08)	(0.10)		
NASA Publications$_{i.t}$	-0.01	-0.01		
	(0.07)	(0.09)		
NASA Publications$_{i.t-5}$	-0.23**	-0.20*		
	(0.08)	(0.10)		
NASA Publications$_{i.t-10}$	0.30***	0.41***		
	(0.10)	(0.10)		
NASA Other Output$_{i.t+5}$			0.24	0.42
			(0.53)	(0.55)
NASA Other Output$_{i.t}$			-0.63	-0.89
			(0.40)	(0.47)
NASA Other Output$_{i.t-5}$			0.30	0.17
			(0.29)	(0.36)
NASA Other Output$_{i.t-10}$			-0.27	-0.13
			(0.23)	(0.31)
Controls:				
MSA Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	No	Yes	No	Yes
R^2	0.18	0.54	0.18	0.54
Observations	10,958	10,958	10,958	10,958

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. NASA publications$_{i,t-x}$ are the NASA publication in the MSA lagged x years (2 manufacturing censuses) in hundreds of publications.

Table 4: NASA Publications and Labor's Share – IV Estimates

Dependent Variable:	Labor's Share$_{it}$ * 100			
IV:	Topic Publication Share Lag × National Area Trends		Topic Publication Share 1958 × National Area Trends	
	(1)	(2)	(3)	(4)
NASA Publications$_{i,t-5}$	-0.33**	-0.27**	-0.42**	0.34**
	(0.16)	(0.12)	(0.18)	(0.16)
NASA Publications$_{i,t-10}$	0.39***	0.48***	0.34**	0.45***
	(0.13)	(0.13)	(0.13)	(0.11)
First Stage F-Statistic: NASA Publications$_{i,t-5}$	102.55	102.55	11.29	11.29
Controls:				
MSA Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	No	Yes	No	Yes
R^2	0.54	0.54	0.25	0.58
Observations	11,128	11,128	11,128	11,128

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). IV1 is a shift share instrument where the share is based on the local share of technology categories in year *t*-1 and the shift is the change in publications in a topic area excluding area *j* between *t* and *t* – 1. IV2 is a shift share instrument where the share is based on the local share of technology categories in 1958 and the shift is the change in publications in a topic area excluding area *j* between *t* and *t* – 1. The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. NASA publications$_{i,t-10}$ are the NASA publication in the MSA 10 years (2 manufacturing censuses) in hundreds of publications.

Table 5: NASA Publications and Labor's Share – Robustness

Additional Controls:	1960 Defense Spending Per Capita	1962 % Scientist Defense Fund	1961 Computer Per Capita × Year	1960 College Grad % × Year	College Grad %	1960 University Enroll × Year	1963 Research Scientist Per Capita × Year	State × Year	Industry × Year
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
NASA Publications$_{i,t-5}$	-0.27**	-0.24	-0.28**	-0.25	-0.20*	-0.28**	-0.28**	-0.33	-0.25*
	(0.12)	(0.17)	(0.12)	(0.15)	(0.11)	(0.11)	(0.14)	(0.21)	(0.14)
NASA Publications$_{i,t-10}$	0.44***	0.48***	0.45***	0.37**	0.41***	0.45**	0.42***	0.37	0.44**
	(0.12)	(0.18)	(0.15)	(0.15)	(0.10)	(0.11)	(0.13)	(0.23)	(0.17)
R^2	0.51	0.52	0.52	0.53	0.54	0.52	0.55	0.54	0.55
Observations	11,263	11,363	11,263	11,363	10,629	11,363	11,363	11,363	11,363
Baseline Controls:									
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. The entries in each column and panel reports the results of estimating model (8). The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. All regressions are weighted 1958 Employment in the industry-MSA cell. NASA publications$_{i,t-10}$ are the NASA publication in the MSA 10 years (2 manufacturing censuses) in hundreds of publications.

Table 6: NASA Publications and Labor's Share – By Skill

Dependent Variable:	High Skill Labor's Share$_{it}$ * 100		Low Skill Labor's Share$_{it}$ * 100	
	(1)	(2)	(3)	(4)
NASA Publications$_{i.t+5}$	-0.09	-0.09	-0.22***	-0.19***
	(0.06)	(0.11)	(0.05)	(0.06)
NASA Publications$_{i.t}$	0.16**	0.20*	0.20***	0.26***
	(0.07)	(0.10)	(0.08)	(0.09)
Controls:				
MSA Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	No	Yes	No	Yes
R^2	0.18	0.26	0.22	0.61
Observations	11,363	11,363	11,363	11,363

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2012. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. NASA publications$_{i,t-x}$ are the NASA publication in the MSA lagged x years (2 manufacturing censuses) in hundreds of publications.

Table 7: NASA Publications and Labor's Share – By Initial Levels

Initial Stratification:	1958 Average Annual Income		1958 Patent		1958 Labor Share		1958 Capital Labor Ratio	
	Low	High	Low	High	Low	High	Log	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NASA Publications$_{i,t-5}$	-0.11	-0.36**	-0.20	-0.34*	-0.33**	-0.26	-0.35	-0.23
	(0.22)	(0.15)	(0.21)	(0.17)	(0.15)	(0.18)	(0.21)	(0.15)
NASA Publications$_{i,t-10}$	0.00	0.70***	0.31	0.51**	0.36*	0.48***	0.21	0.55**
	(0.16)	(0.24)	(0.20)	(0.20)	(0.19)	(0.18)	(0.19)	(0.21)
R^2	0.52	0.55	0.52	0.54	0.48	0.43	0.44	0.57
Observations	5,679	5,684	6,248	5,145	5,676	5,687	5,673	5,690
Baseline Controls:								
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. The entries in each column and panel reports the results of estimating model (8). The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. All regressions are weighted 1958 Employment in the industry-MSA cell. NASA publications$_{i,t-10}$ are the NASA publication in the MSA 10 years (2 manufacturing censuses) in hundreds of publications.

Table 8: NASA Publications and Labor's Share – By Industry NASA linkages

Industry Stratification:	NASA Contracts Received		NASA Labor Market Pooling		Purchase from NASA		Sell to NASA	
Sample:	Yes	No	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NASA Publications$_{i,t-5}$	-0.32	-0.22*	-0.44*	-0.15	-0.44**	-0.32	-0.57**	-0.28*
	(0.24)	(0.12)	(0.12)	(0.17)	(0.21)	(0.20)	(0.27)	(0.12)
NASA Publications$_{i,t-10}$	0.79***	0.21	0.64**	0.32**	0.64**	0.46**	0.73**	0.48***
	(0.27)	(0.15)	(0.24)	(0.13)	(0.24)	(0.18)	(0.28)	(0.16)
R^2	0.44	0.56	0.48	0.53	0.47	0.50	0.34	0.52
Observations	4,036	7,327	4,574	6,789	4,655	4,312	2,542	6,425
Baseline Controls:								
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. The entries in each column and panel reports the results of estimating model (8). The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. All regressions are weighted 1958 Employment in the industry-MSA cell. NASA publications$_{i,t-10}$ are the NASA publication in the MSA 10 years (2 manufacturing censuses) in hundreds of publications.

Table 9: NASA Publications and Labor's Share – By Technology Type

Dependent Variable:	Labor's Share$_{it}$ * 100					
Publication Technology:	Chemical	Computers & Comm.	Drugs & Medical	Elect. & Electronics	Mechanical	Other
	(1)	(2)	(3)	(4)	(5)	(6)
NASA Publications$_{i,t-5}$	-5.71***	-1.26**	-1.94	-1.61***	-1.64**	-0.42**
	(0.10)	(0.53)	(1.68)	(0.46)	(1.62)	(0.18)
NASA Publications$_{i,t-10}$	6.98***	2.66***	5.13	2.16***	3.92***	0.75***
	(2.42)	(0.62)	(3.18)	(0.40)	(1.17)	(0.19)
Controls:						
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	No	Yes	No	Yes
R^2	0.53	0.53	0.54	0.52	0.53	0.52
Observations	10,554	10,756	10,319	11,188	10,892	11,226

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2002. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). The main entries are coefficient estimates with standard errors clustered at the MSA and industry level in parentheses. NASA publications$_{i,t-10}$ are the NASA publication in the MSA lagged 10 years (2 manufacturing censuses) in hundreds of publications.

Table 10: NASA Publications and Labor's Share - Components Effects

Dependent Variable:	Log(Employment)	Log(Annual Labor Income)	Log(Capital Labor Ratio)
	(1)	(2)	(3)
NASA Publications$_{i,t-5}$	0.012	-0.004	-0.017
	(0.014)	(0.006)	(0.022)
NASA Publications$_{i,t-10}$	0.027**	0.007	-0.098***
	(0.011)	(0.010)	(0.024)
Observations	11,363	11,357	11,357
Controls:			
MSA Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2012. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). The main entries are coefficient estimates with standard errors clustered at the MSA level in parentheses. All regressions are weighted 1958 Employment in the industry-MSA cell. NASA publications$_{i,t-x}$ are the NASA publication in the MSA lagged x years (2 manufacturing censuses) in hundreds of publications.

Table 11: NASA Publications, Patents and Mark Ups

Dependent Variable:	Patents	Citation Weighted Patents	Mark Up: Publication State	Mark Up: No Publication State
	(1)	(2)	(3)	(4)
NASA Publications$_{i.t-5}$	-0.64	1.77	0.001	-0.008
	(0.81)	(4.80)	(0.008)	(0.025)
NASA Publications$_{i.t-10}$	0.95	6.96	0.014	0.175***
	(1.14)	(9.65)	(0.015)	(0.048)
Controls:				
MSA Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
R^2	0.29	0.24	0.43	0.32
Observations	11,363	11,363	3,360	4,345

Notes: Sources Manufacturing Census and NASA publication data from 1947 to 2012. The unit of observation for MSA-Industry. Each column reports the results of the estimation of model (8). The main entries are coefficient estimates with standard errors two way clustered at the MSA X industry level in parentheses. NASA publications$_{i,t-10}$ are the NASA publication in the MSA 10 years (2 manufacturing censuses) in hundreds of publications.