

The “Weighty” Manufacturing Sector: Transforming raw materials into physical goods

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Abstract

The manufacturing sector encompasses a diverse set of industries that are involved in the transformation of raw materials into physical goods. Over the last two decades, the U.S.’s manufacturing value added (MVA) has slightly grown, however, the U.S.’s percentage of global MVA has declined due to China’s exponential rise. Likewise, in contrast to net employment in the U.S. economy, which has increased, net employment in manufacturing (while growing slightly since 2010) is significantly lower than in the 1980s. As a whole, the manufacturing sector involves higher value added per capita employed, a greater proportion of the labor force with education at the high school level or below while having on average higher wages for that labor force, higher industry spending on R&D, and fewer private equity/ venture capital deals financing new ventures than non-manufacturing industries such as services (including software). The U.S.’s relatively high R&D spending on manufacturing (66% of industrial R&D) and comparatively low manufacturing value added (14%) is at least in part due to the globalization of manufacturing facilities in the last decade. The above said, drawing implications from sector-wide trends can be misleading because of the variation in these indicators across sub-sectors. At the five-digit NAICS code level, the top sources of employment are animal processing, aerospace products, and printing (on various materials including textile, metal, plastics); the top sources of revenue are petroleum refineries and automotive; and the top source of R&D spending is pharmaceuticals. Considering the sector’s diversity will be critical to understanding productivity and labor outcome effects, and appropriate policy responses, if any.

1. Introduction

The U.S. Manufacturing sector comprises establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products (NAICS 2017). The sector is composed of diverse industries with widely varying value added, workforce size and composition and level of research and development effort. Manufacturing has historically played a significant role in productivity. Jorgenson (2001, 2016) suggests that advances in microprocessors alone were associated with 50% of total factor productivity growth in the U.S. and world-wide in the 1990s.

Overall U.S. manufacturing value added has grown in real terms since the 1980s and 1990s (as far back as public data allow us to observe), in addition to real growth in U.S. private R&D spending by manufacturing industries, with only employment in the sector declining during the same period¹. Manufacturing has seen a relative decline on all three dimensions, accounting for a smaller share of total U.S. value added², a smaller (though still majority) share of U.S. industrial R&D funding and a smaller share of total employment. The relative role of

¹ U.S. manufacturing employment also went from 19% of total employment in 1982 to 8.7% in 2015 (and still falling slightly as of 2019, beyond our R&D funding dataset, at 8.5%).

² MVA share of U.S. Gross Value Added shifted from 16.7% in 1997 to 12.1% in 2015 (i.e. a 27.9% relative decline.)

manufacturing is not homogenous across value added, R&D funding and employment. Manufacturing is a disproportionate source of private R&D spending relative to its share of employment and GVA^{3,4} and is also a disproportionate center of value-creation relative to the share of the labor force that it employs⁵. Both of these features have been magnified over the last two or three decades, in conjunction with the increase in U.S. multinational production and research and development activity abroad.

2. A Brief History of Manufacturing Technologies and Systems

U.S. manufacturing began in the 17th and 18th centuries as a craftwork system imported from Europe to the American colonies (Epstein, 1993). Craftwork was performed by skilled artisans, often working with tools that they owned themselves. Labor was organized into master craftsmen with apprentices, or in small firms. In this period, most craftwork was for domestic consumption, and exports were dominated by raw materials (Shepherd and Williamson 1972).

In the mid-18th century, what later came to be known as the first industrial revolution emerged in Great Britain. This revolution would eventually reach its maturity in the United States during the first quarter of the 19th century (Crafts 1996). The first industrial revolution shifted the sources of production power from human and animal toward chemical sources such as coal and wood, and water sources such as riverside mills (Crafts 1996). Faced with abundant materials but scarce, relatively skilled labor, U.S. manufacturers in this period strongly favored innovations in mechanization (even compared with Great Britain) (Rosenberg, 1975). This mechanization reduced the demand for labor on the production line but increased material waste and produced new demand for skilled machinists to construct the machines. At the same time as the demand for skilled machinists grew, the shift in production organization from artisanal work to factory production saw a decline in the demand for skilled artisanal labor while shifting demand toward less skilled production labor within the factory (Goldin and Katz 1998).

After the first and into the second industrial revolution, U.S. manufacturing saw the emergence, national prominence and international export of the “American System,” a mechanized approach to producing separate, interchangeable parts that made up final goods (Hounshell 1984). Eli Whitney originally popularized the concept of interchangeable parts in response to the needs of American small arms manufacture for high performance, easier repair, maintenance and logistics (Hounshell 1984). Progress toward interchangeability was further developed by entities such as the Springfield Armory (Ford 2005). In addition to facilitating higher production volumes, interchangeability also expanded opportunities for the division of labor (Tyson 1990). Novel modes of organizing production activity at larger scales were driven in large part by the demand of U.S. armories which emerged in the late 18th century and proliferated in the first quarter of the 19th century. Production volumes grew around U.S.

³ The ratio of R&D spending within manufacturing relative to its share to GVA share went from 4.52 in 1997 to 5.45 in 2015 (i.e. a 21% relative increase). The share of research funding proportional to employment in manufacturing grew from 1982 to 2015 and was “overrepresented” on a per-capita basis by a factor of 5.

⁴ The manufacturing share of GDP parallels the trajectory of its share of GVA.

⁵ Manufacturing productivity per capita employed (measured as its share of the U.S. GVA versus its share of employment) is higher than that of the overall U.S. economy by a factor of 1.39. Manufacturing’s share of GVA relative to its share of employment has grown since 1997 (the first available U.S. MVA data) from a ratio of shares at 1.18 to a ratio of 1.40 in 2016

conflicts such as the Mexican-American War and the American Civil War as well as arms production for national and international use in the later 19th and early 20th centuries (Smith 1980; Smith 1985; Malone 1988). By the 1870s and the coming of the second industrial revolution, major productivity gains had been achieved through specialized labor and tools (Atack, Margo and Rhode 2019) and innovations in power sources (e.g. from coal to oil) (Mokyr 1998). As infrastructure, transportation, and communication technologies expanded and improved, production was able to further increase in scale, scope, and complexity. Along with increases in these dimensions came an enlarged role for salaried managers who did not own the industrial enterprises but rather were organized according to functions within the overall system of the firm, such as sales, purchasing, or research (Chandler 1990). The organizational implications of the increasing scale economies of production gave rise in the early 20th century to what became known as the American system of mass production (Hounshell 1984). Under mass production, further division of labor and specialization were made possible by the realization of interchangeable parts combined with a high degree of product and process standardization under organizational structures such as the assembly line and scientific management approaches pioneered by Frederick Winslow Taylor (Taylor 1914; Hounshell 1984; Chandler 1990). These innovations also drove a further complementarity between capital and low skilled labor (Lafortune, Lewis and Tessada 2019). Standardization in tools, processes and products would remain a driving feature of production into the post-war era (Mowery and Rosenberg 1999).

After a slowdown in productivity growth in manufacturing from the 1960s to 1970s (Hulten and Schwab 1984), U.S. manufacturing in the mid-1970s and 1980s experienced what some have referred to as the third industrial revolution (Greenwood 1997; Mowery 2009). Manufacturing tasks shifted from humans and active machine control toward industrial robots and computer numerical control (CNC) systems (Nichols 1976; Bollinger and Duffie 1988; Moore 1997). Flexible manufacturing exploited CNC and other systems to allow medium sized batch production. This batch production enabled product variety over the low-variety scale economies of mass production (Browne et al 1984; Buzacott and Yao 1986). Human resource management approaches such as employee training programs and flexible job assignments also expanded (Bartel 1994; Ichniowski, Shaw and Prennushi 1995).

In contrast to the American system of mass production, shifts associated with the third industrial revolution coincided with higher demand for skilled labor (Katz and Murphy 1992; Autor, Levy and Murnane 2003; Autor and Dorn 2013). In some contexts, changes in the methods of production coincided with changes in the organization of production: from mass production, product standardization and strict task specialization for equipment and personnel toward flexible manufacturing and lean production approaches (Ohno 1988; Mansfield 1993). Lean manufacturing, pioneered at Toyota through the Toyota Production System (TPS), differed from the material-rich roots of early U.S. manufacturing by focusing on minimizing material as well as other resource wastage (Womack, Jones and Roos 1990; Shah and Ward 2003). The system established just-in-time manufacturing strategies, which encouraged firms to entwine production and supply chains with the goal of narrowing the lead time between production and suppliers and time within production (Cheng and Podolsky 1996; Sakakibara, Flynn and Schroeder 1997). Among U.S. manufacturers, lean manufacturing methods were adopted, among other places, in metal fabrication, computer, electrical machinery and automotive production (Swamidass 2007). U.S. firms did not adopt all dimensions of TPS, including due to

concerns around possible limitations on creativity and innovation (Mehri 2006), keeping many traditional compensation and labor relations arrangements (Doeringer, Lorenz and Terkla 2003).⁶

Throughout the third industrial revolution, multiple manufacturing contexts actively pursued increasing the modularity of designs, led by computer hardware and other electronics. Modular computer systems composed of smaller, simpler subsystems (including such elements as hard disk drives and microprocessors) paralleled rapid innovations in component-specific performance that did not require costly (from the perspective of both time and money) total-system overhauls. This modularity in design in some cases was mirrored in the design of organizations and supply chain composition of modern industries (Baldwin and Clark 2000; 2003; Colfer and Baldwin 2016). Suppliers also often took an active role in the innovative process (Helper and Sako 1995). Increasing modularity, including in the organization of suppliers, coincided with an increasing globalization of manufacturing supply chains (Gereffi, Humphrey and Sturgeon 2006). At the same time, system-level innovations were often associated (often temporary) reintegration of modular elements to facilitate technologies that affected characteristics across modular boundaries. The integrated circuit, a key innovation in microprocessors and enabling technology across the U.S. economy (Bresnahan and Trajtenberg 1995), was in itself an integration of components, not the modularization of a system (Moore 1965); other components, such as lasers, saw continuing integration during the 20th and 21st centuries (Liu et al 2007). Drawing on industries such as computer hardware and other electronics, academics hypothesized a dynamic of modularity, and integration in contrast, increasing and decreasing apace with technological shifts (Chesbrough 2003).

Organizational innovations to manufacturing continue to evolve in the 21st century. New innovations in information technology continue to be incorporated into process development (Bartel, Ichniowski and Shaw 2007). Automation has begun to include collaborative dimensions, bringing workers into direct production roles supported by robots (Kaber and Endsley 2004; Cherubini et al 2016). Although, collaborative robots are in their infancy and are unlikely to be appropriate to all settings (Hayes and Scassellati 2013). Additive manufacturing approaches present new possibilities for small batch, high variety production with the promise of mass customization beyond even flexible manufacturing approaches (Fralix 2001; Atzeni and Salmi 2012; Mellor, Hao and Zhang 2014) and material savings complementary to lean manufacturing approaches (Yossi 2013). That said, additive manufacturing is likely to be limited, at least in the near term, in the complexity of components that it can build and the degree of economically feasible customization that it enables limiting its appropriateness in a wide range of contexts (Sheffi 2013; Bonnin-Roca et al 2017a). Further, it is not clear what percentage of the manufactured economy warrants customization.

U.S. manufacturing both historical and today has never been a monolith of organizational modes or production technology. Though lean and flexible approaches have become prominent trends in manufacturing, the American system of mass production continues in new permutations as does the development of new automation technologies that hold potential to transform the nature of work (Mindell 2015). Evolving and innovative supply chain strategies built around short product life cycles and make-to-order production link production organization with distribution in sectors such as retail (Gallien, Le Tallec and Schoenmeyr 2004; Caro and Gallien

⁶While already strong performers adopting TPS realized inventory-to-sales reductions, weaker performers saw an increase in their ratio of inventory-to-sales (Swamidass 2007).

2009). Additive manufacturing technology raises new and diverse possibilities for production models from food to plastics to metals (Herrigel 2010) but which are likely to only supplant existing approaches in some contexts and sectors (Sheffi 2013; Bonnin-Roca et al 2017a). Through all of these changes, large scale, mechanized systems with intellectual roots in the 19th and even 18th century history of U.S. manufacturing continue to hold a major role informed by subsequent innovations (Kumar and Ando 2010; Hu 2013; Achillas et al 2015).

3. Manufacturing Value Added and Research and Development

3.3 US and Global Value Added

The United States has seen growth in its gross value added (GVA) over the last 25 years, and modest growth in its share of world GVA from 2011 to 2016 after year-on-year decline since 2001 (World Bank 2019).⁷ Alongside this broader trend, the U.S. has also seen growth in manufacturing value added in real terms (indeed, at a higher rate than the growth of key manufacturing countries such as Germany or Japan), and at the same time a decline in its global share of MVA since 2000 (without any sustained increase in its MVA share over more than two years), due in large part to the exponential rise in China's MVA. In terms of both the U.S. real value added and share of global value added, non-manufacturing sectors, such as services, has outperformed the manufacturing sector (with larger increases in real value added and smallest declines in the share in global value added) (World Bank 2019).

Increased competition with U.S. manufacturing from international sources has the potential to affect survival and U.S.-based activities of U.S. domestic firms. Evidence from U.S. manufacturing plants suggests that exposure to international trade has the potential to drive out low productivity firms or plants but (with adequate international demand) allow high performing firms to sell more abroad (Bernard et al 2003). Firm and local market level evidence suggests that exposure to Chinese competition in the U.S. and foreign markets reduced R&D expenditure and employment by U.S. manufacturing firms as they scaled back operations (Dorn et al 2016; Autor, Dorn and Hanson 2016). While in 1970s and 1980s manufacturing productivity did not converge across countries (Bernard and Jones 1996), in the last two decades less productive countries have seen greater manufacturing productivity gains than the most productive countries (Rodrik 2012).

⁷ There is only limited global data available for gross value added by nation, particularly China, which lacks data altogether: the U.S. share of GVA is likely less than reported by the World Bank and perhaps declining more sharply with growth in unmeasured nations.

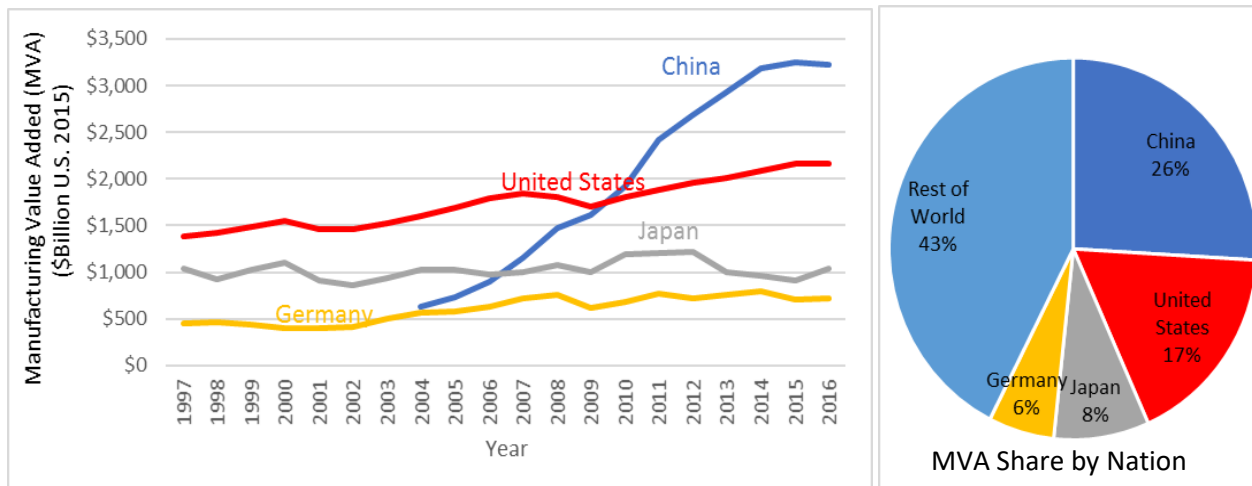


Figure 1 Manufacturing Value Added of Top 4 Manufacturing Nations (1997-2016)

U.S. manufacturing has seen a decline in its share of U.S. value added (BEA 2019). While manufacturing value added stagnated in real terms in the period 1997-2015, other sectors such as services grew. Thus, the relative role of manufacturing in the overall value added of the economy decreased (see Figure 2). Outside of services, manufacturing and information (reported in the following table) the largest nongovernmental sectors by value added are finance (21%) and retail and wholesale trade (10%). Though the greatest proportional growth in 1997-2015 was in mining (89% increase in VA 1997-2015), the largest real growth was in services and finance, with manufacturing among the slowest growing sectors proportionately and in real terms (BEA 2019).

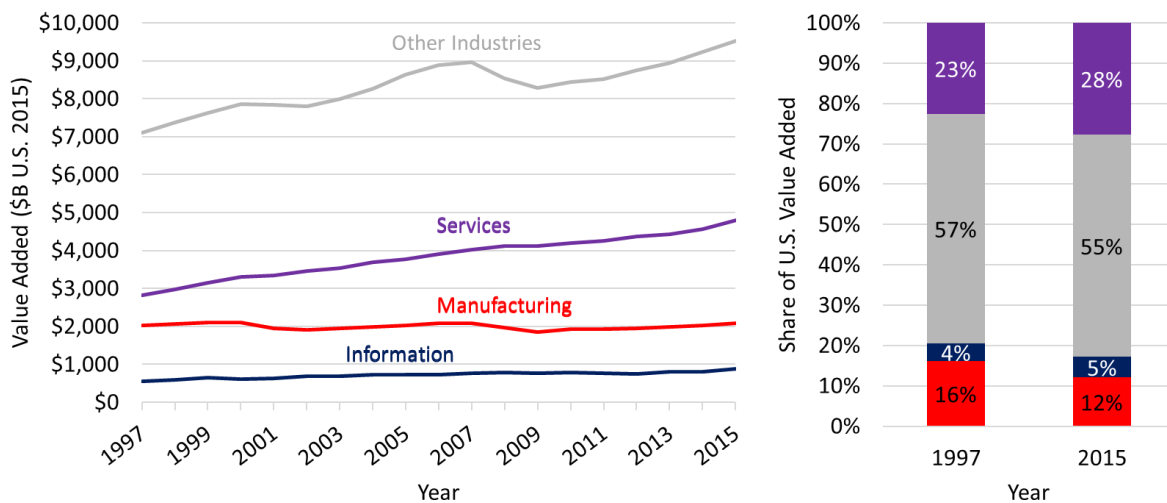


Figure 2 Manufacturing Value Added by Sector (BEA 2019)

3.2 US and Global R&D Spending

While the United States has seen growth in manufacturing R&D spending since the 1980s, spending in the period 2008-2015 was mostly stagnant in a similar trend to Japan and Germany (the nations with the third and fourth greatest manufacturing R&D spending). In contrast, Chinese manufacturing R&D spending more than doubled in the same period,

exceeding U.S. spending in 2013 (OECD 2019).⁸ Figure 3 captures these trends in R&D spending by the manufacturing industry in key nations. The named countries' share of global manufacturing R&D activity is overstated in the figure, because the broadest available dataset for 2015 (the latest available year with broad, reliable international data) includes data from the China, the U.S., Japan, Germany, the OECD nations, Taiwan, Argentina, and Romania, but not the rest of the world.

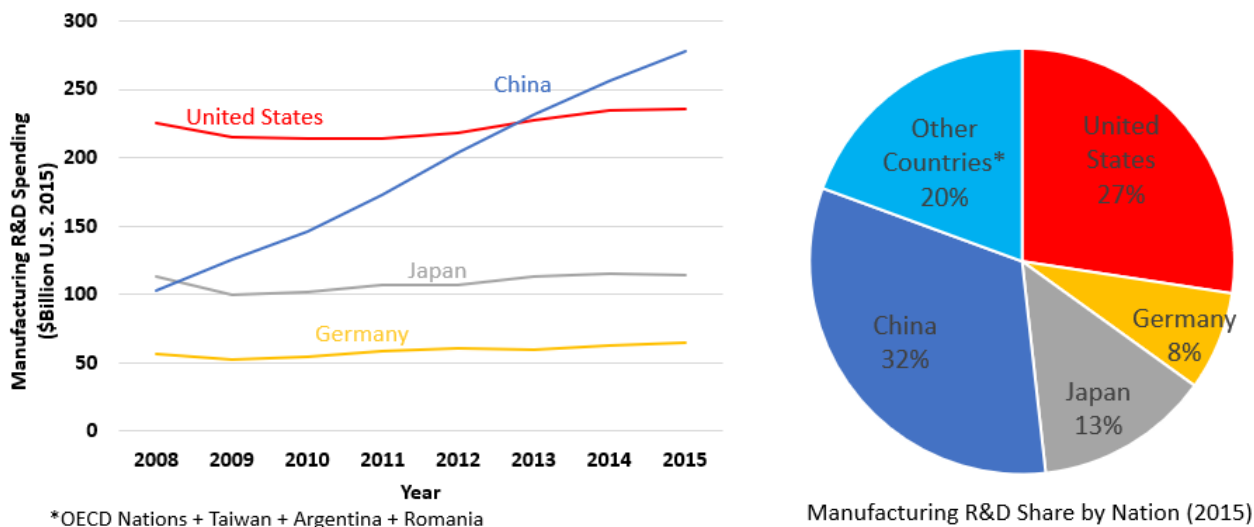


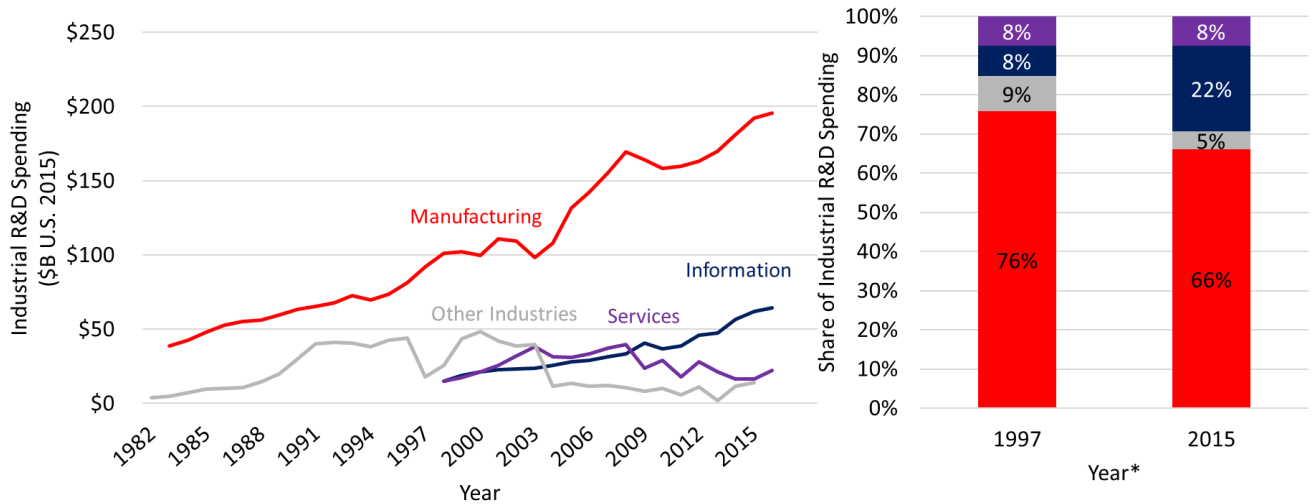
Figure 3 Manufacturing R&D Spending by Top 4 R&D Spending Nations (OECD 2019)

Between 1982 and 2015, the U.S. rate of federal R&D funding declined as a relative share of total R&D funding (NSF 2018, AAAS 2018), with industrial R&D funding growing relative to federal funding over the same period (See Appendix K). Industrial and federal R&D show significant differences in the funding of basic versus applied research: while 30-36% of overall federal funding was allocated to basic research over the period of 2006-2015, in 2015 only 5.5% of industry R&D spending was directed toward basic research, the rest going to applied research and development.⁹ Arora et al (2015) show declining R&D spending and capability-building by U.S. companies in basic research. Fleming et al (2019) suggest that companies are increasingly relying on federally-supported research.

⁸ While offering the most complete international data on R&D spending by nation and industry, the OECD Science, Technology and Patents Database is based on a different definition of R&D spending from that used by the U.S. government (and OECD notes that U.S. R&D inputs to its database are based on a different definition). OECD's research and development (R&D) "comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge (including knowledge of man, culture and society) and the use of this knowledge to devise new applications." The inclusion of social sciences expands the scope of relevant R&D activity outside that used within the United States and thus may understate the level of non-social science U.S. R&D spending relative to other countries.

⁹ Federal funds to industry were also disproportionately allocated to applied research and development, with 8% of funds going to basic research.

Within the United States, manufacturing remains the dominant source of industrial R&D. Industrial R&D spending originating from manufacturing grew significantly in real terms over the period 1982-2015 (NSF 2018). However, after 1997, this growth in manufacturing R&D was accompanied by growth in the spending from other sectors including services and information, such that the overall share of industrial R&D spending from manufacturing declined (see Figure 4).



*While manufacturing and overall R&D data extend to 1982, information and service data begin in 1997

Figure 4 U.S. Industrial R&D Spending by Sector (NSF 2018)

4. The Manufacturing Labor Force

The IPUMS CPS Annual Social and Economic Complement microdata from 1968 to 2018 reveal differences between the manufacturing and non-manufacturing labor force along several demographic dimensions, including educational attainment, age, gender, and wage and salary income groups. Each individual observation in the data is weighted by the ASEC population weight. Figure 5 shows the magnitude of the labor force each year in manufacturing and nonmanufacturing. Note the decline in the absolute value of the manufacturing labor force post 1981.

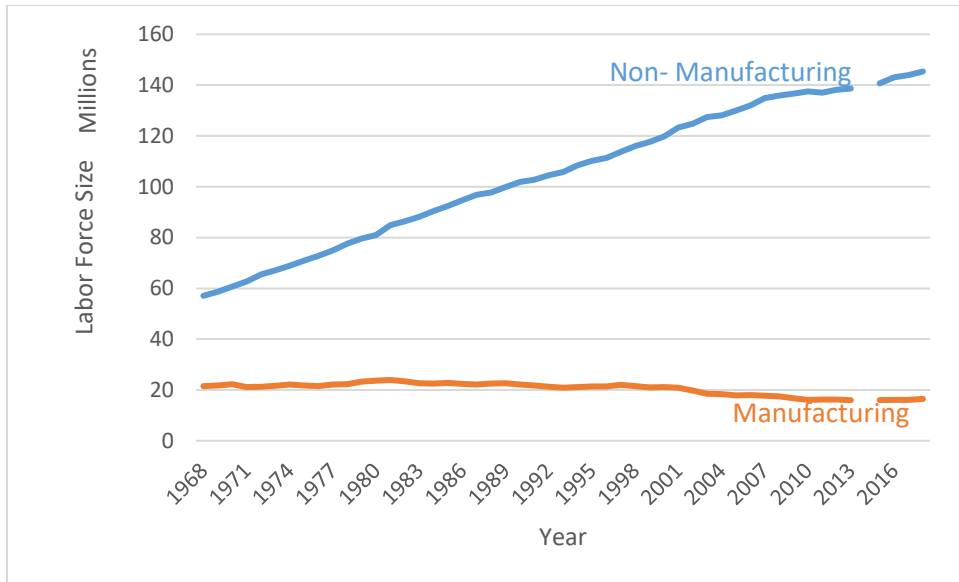


Figure 5 Absolute Magnitude of the Non-Manufacturing and Manufacturing Labor Force, IPUMS – CPS, ASEC microdata¹⁰

4.1 Human Capital and Demographics of the Labor Force

Educational attainment, as measured by years of formal education, has risen for the overall labor force, manufacturing sector, and manufacturing subsectors. Across the economy, the proportion of workers with a high school (HS) education or less has declined across the last five decades. Berman et al. (1994) argue that labor-saving technological change is the leading cause of this trend. Berman et al. (1998) find further international evidence of manufacturers increasing demand for skilled workers and increasing skill premiums, in line with skill-biased technological change hypothesis.

As can be seen in Figure 6, the manufacturing sector (bold orange line) consistently has a higher proportion of workers with a HS education or less relative to non-manufacturing sectors (bold blue line); each year the non-manufacturing labor force is comprised of 8-12 percentage points more of higher educated workers relative to the manufacturing sector overall.

¹⁰ In Figure 5, 2014 is omitted to allow for use of consistent weighting by the ASEC population weight, as the CPS underwent an experimental redesign.

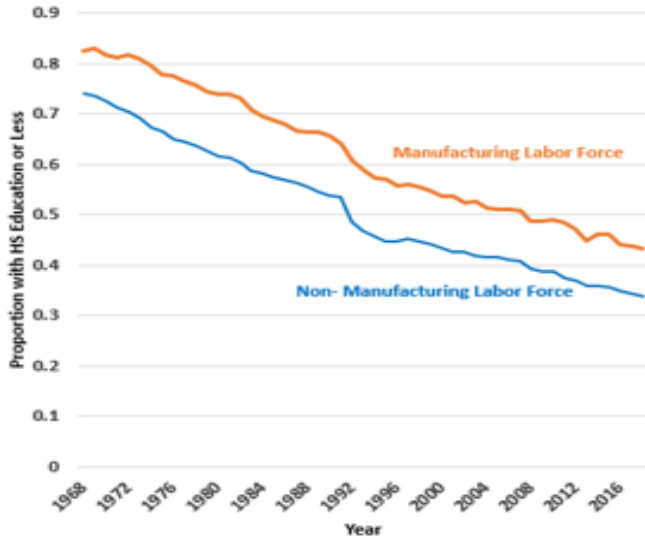


Figure 6 Manufacturing and Non-Manufacturing Labor Force Educational Attainment exhibiting a consistent difference. IPUMS- CPS ASEC microdata (1968- 2018)

4.2 Worker Class and Wage and Salary Income

Worker class falls into one of four categories: private wage or salary worker, federal or state government employee, self-employed (incorporated or unincorporated), or unpaid family worker. The manufacturing industry’s labor force has remained nearly completely private wage or salary workers: 98% in 1975 and 95% in 2015. In the non-manufacturing sector , private wage and salary workers have increased over time: 67% in 1975 and 74% in 2015. Figure 9 shows annual individual wage and salary income, CPI adjusted to 2017 dollars, between 1968 and 2018 (as shown in Figure 7). While the proportion of non-manufacturing workers with earnings less than \$10,000 declines over time, the proportion of the manufacturing labor force earning less than \$10,000 (2017 dollars) remains less than the proportion of the non-manufacturing labor force. The total proportion of the manufacturing labor force whose earnings fall in the categories between \$10,000 and \$250,000 is also higher than the non- manufacturing labor force.

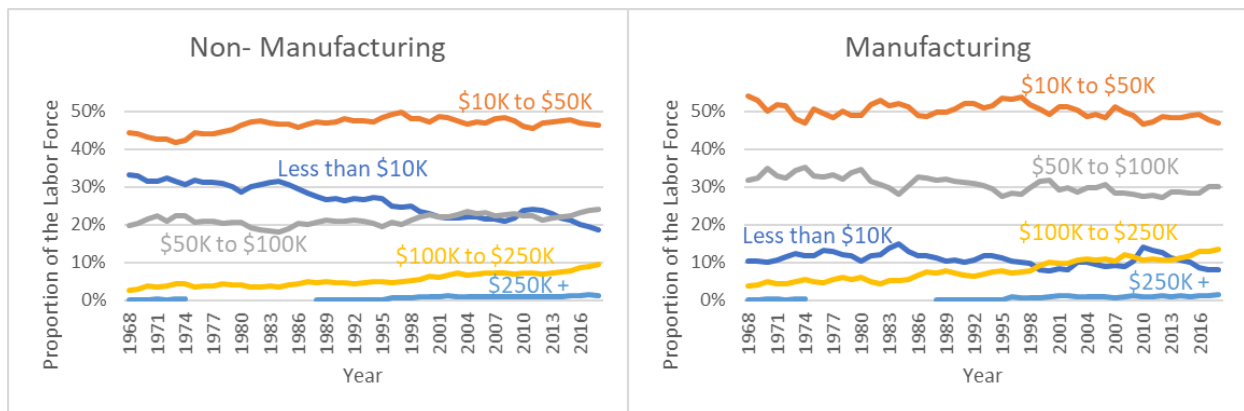


Figure 7 Individual Wage and Salary Income Categories, CPS Microdata (1968 to 2018)

5. Manufacturing Share of Value Added and Share of R&D Funding

5.1.1. Disproportionate R&D Funding from Manufacturing Relative to MVA

Manufacturing historically and currently makes up a disproportionate source of overall industrial R&D funding in the United States: about 96% in 1982, and about 66% in 2015. Though shrinking proportionally, R&D funds from manufacturing grew in real terms by 197% in the same period. Manufacturing represents a declining share of the US labor force (about 8%) (BLS 2019)¹¹ and of US economic output (about 14%) (BEA 2019): given declines in manufacturing employment during the same period, the per-capita share of research funding from manufacturing *grew* from 1982 to 2015 (“overrepresented” on a per-capita basis by a factor of 5 in R&D funding).

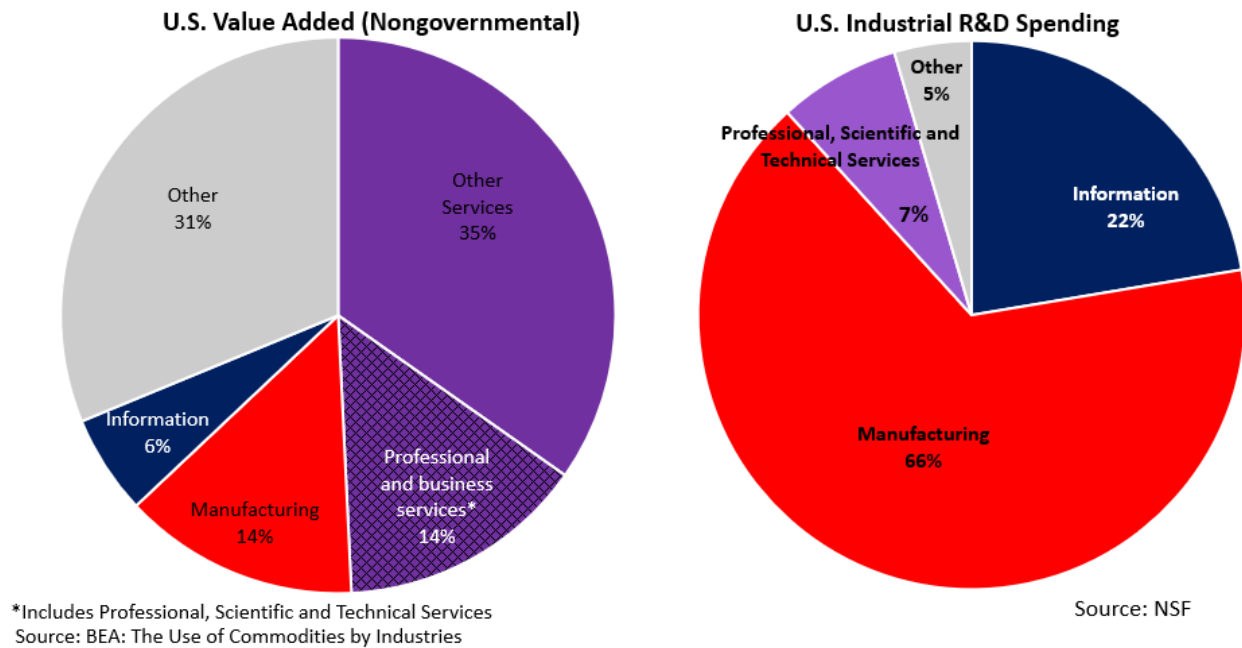


Figure 8 Share of Value Added and Industrial R&D Spending by Sector (2015)

5.2 Hypotheses and Evaluation

In the following subsections, we propose and evaluate three hypotheses to account for the disproportionate share of U.S. industrial R&D spending (as measured by NSF) from manufacturing. Our first hypothesis is that other sectors of the economy may underreport their R&D spending, possibly due to incentives in the R&D Credits available under the U.S. tax code or because research activities that are not performed through traditional R&D channels are not counted by NSF. Our second hypothesis is that the returns from manufacturing R&D may also accrue to nonmanufacturing sectors, for instance through R&D embodied in manufactured capital or through the development of General-Purpose Technologies (GPTs) using manufacturing R&D funds. Finally, we hypothesize that the returns to domestic manufacturing

¹¹ While the total share of the US economic output from manufacturing has declined, the labor-efficiency of manufacturing (measured in Manufacturing Value Added per capita employed in the sector) relative to the rest of the economy (measured in Gross Valued Added per capita employed) has increased.

R&D may be realized abroad, for instance by multinational firms, and thus not reflected in value added statistics from U.S. manufacturing.

5.2.1 Mismeasurement and Reporting Incentives

We examine three possible sources of mismeasurement of R&D spending and conclude that they cannot account for the dominance of manufacturing R&D spending.

The first possible source is measurement error through sampling bias in the NSF's data collection process for industrial R&D spending. The NSF used the "Business R&D and Innovation Survey" (BRDIS) from 2008 until the 2016 survey cycle. The BRDIS defines R&D as "planned, creative work aimed at discovering new knowledge or developing new or significantly improved goods and services."¹² R&D returns manifest outside of manufacturing, or manufacturing does not appropriate all returns. The survey covers a population consisting of all firms in the Business Register, with or without known R&D activities. As part of the survey, firms are asked to report whether they engage in R&D activity and how many employees are engaged. NSF notes the risk of bias from different definitions of R&D but identifies government contractors and R&D service companies as the major risk items, possibly *overstating* their level of R&D spending activity. Industrial R&D funding as reported by NSF does not include funds from the federal government for performance so that federal funding activity is not included in the dominance of manufacturing industrial R&D spending (NSF 2018), and R&D service providers are already measured in the NSF data to account for a share of industrial R&D spending less than one sixth that of manufacturing. These potential sources of measurement error in the NSF's survey methodology appear unlikely to account for the dominance of manufacturing in R&D spending.

The second possible source of mismeasurement is that some spending activities that further R&D objectives are not included in traditional R&D spending channels. For example, venture capital investment is not factored into industry R&D spending as measured by NSF, but nevertheless may support innovation effort from firms which engage in research-like activity (Kortum and Lerner 2001). The Venture Capital and Private Equity (VC/PE) market's nominal value of \$0.53 trillion over the period 2009-2015 (CB Insights 2019) compares with nominal private industrial R&D spending of \$1.76 trillion from 2009 to 2015. Assuming that every dollar spent in the VC and PE market was a form of R&D investment and given that about 3% of VC/PE spending went to manufacturing, manufacturing would still represent at least 52% of nominal combined industrial and venture capital R&D spending. Even under the most expansive

¹² This definition includes a) activities aimed at acquiring new knowledge or understanding without specific immediate commercial application or use (basic research); b) activities aimed at solving a specific problem or meeting a specific commercial objective (applied research); and c) systematic use of research and practical experience to produce new or significantly improved goods, services, or processes (development). The term Research and Development does NOT include expenditures for: routine product testing, quality control, and technical services unless they are an integral part of an R&D project; market research; efficiency surveys or management studies; literary, artistic, or historical projects, such as films, music, or books and other publications; prospecting or exploration for natural resources.

assumptions about the share of VC spending dedicated to research activities, manufacturing would remain the majority source of combined VC and traditional R&D spending (at least 52%).

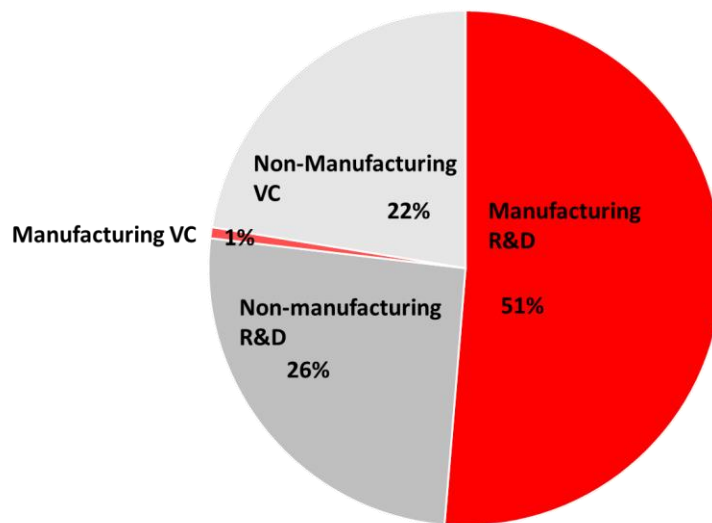


Figure 9 Manufacturing and Nonmanufacturing Shares of R&D and Venture Capital Spending (2009-2015)

The third possible source of error that we examine is differences by sector in the incentives to report R&D spending. U.S. firms have a financial incentive to report their R&D activities under the terms of the Federal R&D Tax Credit, in place since 1981 and established in perpetuity since the 2015 PATH Act. The terms of the credit have been consistent since before the PATH Act, however (CPAJournal 2017). The terms for accessing the tax credit for R&D activity could produce different incentives to report R&D. The credit is available to businesses developing “new, improved, or technologically advanced products or trade processes” (IRS 2019). Qualified applications include wages for qualified services, supplies used and consumed in R&D, contract research expenses on behalf of government and basic research payments to qualified institutions. The credit also places constraints on qualified activities, which must be intended to resolve technological uncertainty, consist of a process of experimentation to resolve that uncertainty and rely on engineering, computer science, biological science or physical science.

Under the conditions for the credit, manufacturing firms may have less incentive to report R&D than other sectors, not more. The credit notably excludes fixed capital, while wages, contracts and supplies are creditable (IRS 2019). Given the capital intensity of manufacturing R&D (Nadiri and Mamuneas 1991), there may be less incentive for manufacturing firms to report their R&D spending than other, less capital intensive sectors (such as information). The credit is also not available for incremental product development (such as post-launch software fixes). One major change brought by the PATH act is that startup businesses with no federal tax liability and gross receipts of less than \$5 million may take the R&D tax credit against their payroll taxes. While NSF does not report data on firm R&D spending by revenue, U.S. firms with fewer than 100 employees accounted for 6.3% of U.S. industrial R&D in 2016 (after the PATH act took effect) (NSF 2019), insufficient to displace the dominance in prior years of manufacturing even if other sectors had proportionately more firms with revenues less than \$5 million.

Finally, we note in Figure 10 that among the largest publicly traded U.S. firms by R&D spending (Price Waterhouse Coopers 2019), manufacturing remains a dominant sector that key firms outside manufacturing such as Google, Amazon and Microsoft help drive the spending of top firms. That is, these firms claim heavy R&D spending but do not displace the dominance of manufacturing, even under the whole population measure of the top 340 publicly traded U.S. firms used by PwC.

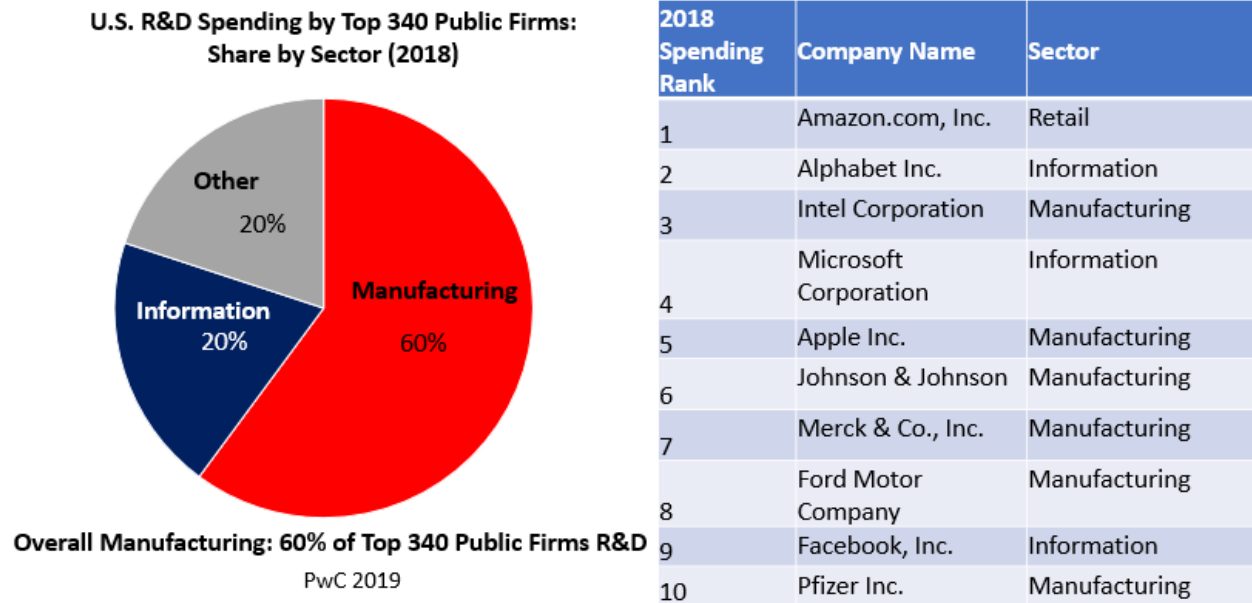


Figure 10 R&D Spending by Sector, Top 340 Public U.S. Firms (Left); Top 10 U.S. Firms by R&D Spending (2018)

5.2.2 Returns Across Sectors and General Purpose Technologies

Our second hypothesis, that the returns to manufacturing R&D may accrue in other sectors of the U.S. economy, is motivated by the literature on General Purpose Technologies: under this framework, manufacturing either embodies its R&D returns in physical goods which are then sold to other sectors or generates technical knowledge that is adapted and appropriated by other sectors.

Our first subcase is motivated by descriptions of GPT embodied in capital (cfe Aghion and Howitt 2002). We evaluate this subcase of the GPT hypothesis using input-output accounts data by subsector from the Bureau of Economic Analysis (BEA 2019). This dataset, collected at the annual level, relates the inputs from individual subsectors of the U.S. economy to other U.S. subsectors and reports the output and value added of each subsector, with subsectors reported at 4 and 5 digit NAICs code levels. In total, the dataset covers 71 subsectors of the economy, each described in terms of the dollar value of its inputs from and outputs to the other 70. We select the 66 of these 71 subsectors which are nongovernmental and construct a time series dataset from 1997 to 2017 relating the inputs from each subsector to every other subsector and subsector outputs and value added by year. For intertemporal comparison, all annual input, value added and output data were adjusted to 2015 dollars in our analysis.

We undertake a simple first order statistical evaluation of the embodiment hypothesis to suggest whether an outsized productivity effect from manufacturing R&D might supply an explanation for its dominant role in R&D spending.

To reconstruct the possible embodiment of R&D in the outputs of manufacturing subsectors, we create a composite variable “intensity adjusted embodied R&D stock” going into each nongovernmental subsector from each top R&D spending nongovernmental subsector (including manufacturing industries but also subsectors under information and technical services). This embodied stock is calculated for each year and subsector in the time series and has the form:

$$S_{j,i,t} = \frac{I_{j,i,t}}{\sum_{k=1}^{66} I_{j,k,t}} R_{i,t}$$

Where $S_{j,i,t}$ is the intensity adjusted embodied R&D stock in subsector j from sector i at time t , $I_{j,i,t}$ is the input to subsector j from i in time t (drawn from BEA), $\sum_{k=1}^{66} I_{j,k,t}$ is the sum of nongovernmental inputs to subsector j and $R_{i,t}$ is a research spending term for subsector i in time t . We test several different constructions of $R_{i,t}$ to account for the time that it takes R&D spending to be realized and find that the “best” fit formulation is a three year running average from sub-sector spending in $t - 2$ to spending in t , as measured by NSF (thus limiting the upper bound of our time series to 2015).¹³

As a preliminary estimate of a relationship between this embodied R&D stock and subsectoral output, we test a Cobb-Douglas production function of the form:

$$O_{j,t} = a \left(\sum_{k=1}^{66} I_{j,k,t} \right)^\alpha \left(\sum_{i \in M} S_{j,i,t} \right)^\beta \left(\sum_{i \in V} S_{j,i,t} \right)^\gamma$$

Where $O_{j,t}$ is the output of subsector j in time t , a, α, β, γ are constant terms, $\sum_{k=1}^{66} I_{j,k,t}$ is the value of intermediate inputs to $O_{j,t}$, $\sum_{i \in M} S_{j,i,t}$ is the sum of intensity adjusted embodied R&D stock from subsectors $i \in M$ where M is the set of high R&D spending subsectors in manufacturing and $\sum_{i \in V} S_{j,i,t}$ is the same for V the set of information and service subsectors with high R&D spending. The analysis reported below excludes high R&D spending subsectors that produce end consumer goods (e.g. pharmaceuticals) and focuses instead on machinery, electronics and various transportation goods.

We perform a simple regression analysis estimating $\ln(O_{j,t})$, giving an equation of the form:

$$\ln(O_{j,t}) = \ln(a) + \alpha \ln \left(\sum_{k=1}^{66} I_{j,k,t} \right) + \beta \ln \left(\sum_{i \in M} S_{j,i,t} \right) + \gamma \ln \left(\sum_{i \in V} S_{j,i,t} \right)$$

¹³ We also test alternate formulations for our intensity measure $\frac{I_{j,i,t}}{\sum_{k=1}^{66} I_{j,k,t}}$, including three and five year averages to reflect accumulation of R&D-embodiment stock, with no improvement of fit.

We do not find strong preliminary evidence to support the hypothesis that manufacturing is a destination for R&D spending because it performs and embodies R&D for other sectors. In Table 1 we report the results of our regression estimating sub-sectoral output from inputs and intensity-adjusted R&D stock from manufacturing and from service and information (see appendix J for estimation output with annual time fixed effects – these effects do not affect our evaluation). Though a basic first evaluation, this simple analysis does not give any preliminary suggestion that manufacturing R&D stock in other sectors could be disproportionately contributing to output relative to information and technical services, which it far outweighs in spending. We note that the coefficient for top manufacturing subsector R&D stock is in fact less than one fifth the coefficient for service and information R&D stock – if manufacturing R&D spending is embodied in inputs to other subsectors, service and information inputs may outweigh it. Thus, embodiment of R&D spending does not appear to account for the dominance of manufacturing.

We also perform several simple linear regressions relating variation in value added, output and year-on-year change in these measures to R&D stock from specific subsectors, without any further evidence of a dominant role for manufacturing (see Appendix I).

Table 1 Regression Outputs for Estimation of Sub-Sectoral Output (BEA, NSF 2019)¹⁴

| Dependent Variable: ln(Output) ($R^2 = .86$) | | | |
|---|---------------------|-----------------------|----------------|
| Independent Variables | Coefficients | Standard Error | P-value |
| Intercept | 0.394 | 0.186436 | 0.034 |
| ln(Intensity Adjusted Top Manufacturing R&D Stock) | 0.022 | 0.007154 | 0.002 |
| ln(Intensity Adjusted Service and Information R&D Stock) | 0.122 | 0.011787 | 4.84E-24 |
| ln(Inputs from Other Sectors) | 0.952 | 0.012809 | 1E-25 |

We do not find preliminary evidence to support GPT as the sole explanation for the outsized role of manufacturing in R&D across all manufacturing subsectors. GPTs not being an explanation for all manufacturing subsectors, however, does not rule out it being an explanatory factor for some subsectors, such as, for example, innovation in microprocessors enabling innovation in other sectors throughout the economy (Jorgenson 2001, 2016).

The second subcase is that manufacturing is a source of GPTs which are adopted and adapted by other sectors. A GPT is a technology of generic function and general applicability, whose efficiency improves over time by continuous innovation and which enables innovation and improvement by users in their own technologies (Rosenberg and Trajtenberg 2004). The third element of this definition suggests sector or firm-specific R&D investment supported by the GPT (Helpman and Trajtenberg 1996; Jovanovic and Rousseau 2005), while many of the sectors

¹⁴ Assuming an intercept $a = 1$, $\ln(a) = 0$ does not alter our core findings.

and subsectors whose growth outperformed that of manufacturing were not engaged intensively in R&D (BEA 2019). Jorgenson (2001, 2016) finds that up to half of U.S. economic growth in the 1990s was associated with advances in information technology and hardware (a form of GPT), including microprocessors (a manufactured good). While we were unable to construct technology-specific factor productivity analysis (cfe Jorgenson in 2001), we also note that top manufacturing R&D spenders include pharmaceuticals and other consumable end-use products, which do not fit the profile of GPT. That is, top sources of manufacturing R&D spending generate products which are not generalist in their function (e.g. pharmaceuticals) or which would directly facilitate further innovation in other sectors in the same manner as information technology or microprocessors. While manufacturing and the semiconductor subsector in particular have historically been a source of GPT, it does not appear that manufacturing R&D spending across all sectors engaged in producing GPTs, nor that the emergence of GPTs from manufacturing is a plausible explanation for its disproportionate share of R&D activity.

5.2.3 MVA Returns Abroad: A Partial Solution to the Puzzle

In this section, we examine the hypothesis that returns to domestic manufacturing R&D are realized abroad and therefore are not reflected in value added statistics that are bounded by country borders. We do so by looking at the activities of US multinational companies (MNCs) in the US and at their foreign affiliates, using publicly available Bureau of Economic Analysis (BEA) data from the US Direct Investment Abroad surveys¹⁵. Statistics on value added and R&D performed within the US exclude the foreign affiliate activities of multinational firms and may hide some significant activity undertaken by these firms. The focus on multinational firms is especially significant given their disproportionate role in performing R&D; the National Center for Science and Engineering Statistics (NCSES)¹⁶ reports that US multinational companies performed seventy-nine percent of all R&D conducted by US-located businesses.

Figure 11 illustrates that concentrating attention on US MNCs – and including all of their global activity – significantly shrinks the gap between value added and R&D performed for manufacturing firms vs non-manufacturing firms. The left hand side of the panel is a bar graph representation of the pie chart from Figure 8 in Section 6.1 and shows the original motivating puzzle: manufacturing firms contribute disproportionately to R&D and yet very little value added results from this. The right hand side of the panel focuses attention on US multinational firms and – importantly – includes both the parent activities and the foreign affiliate activities. By concentrating attention on MNCs – and their global activity – the gap between VA and R&D for manufacturing firms as compared to non-manufacturing firms shrinks significantly.

¹⁵ <https://www.bea.gov/international/di/usdop>

¹⁶ Moris, Francisco. R&D Performance of US-Located Multinational Companies: Results from Multiagency Survey Linking Project. February 2016. National Center for Science and Engineering Statistics. NSF 16-305. <https://www.nsf.gov/statistics/2016/nsf16305/nsf16305.pdf>

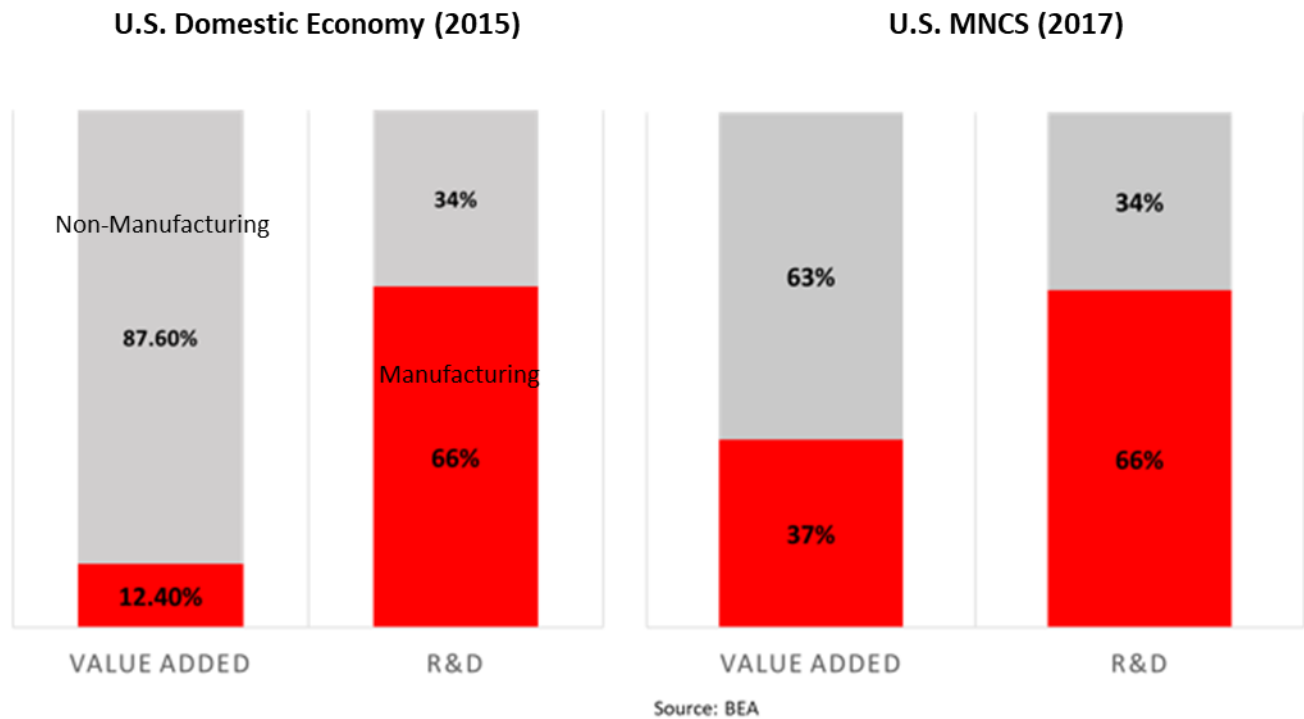


Figure 11 Share of Value Added and R&D Contributed to by Manufacturing vs Non-Manufacturing Firms

Figure 12 provides some insight into why the gap shrinks so much when looking at MNC global activity rather than domestic activity alone: a larger share of value added is abroad than R&D, which is highly concentrated in the US.

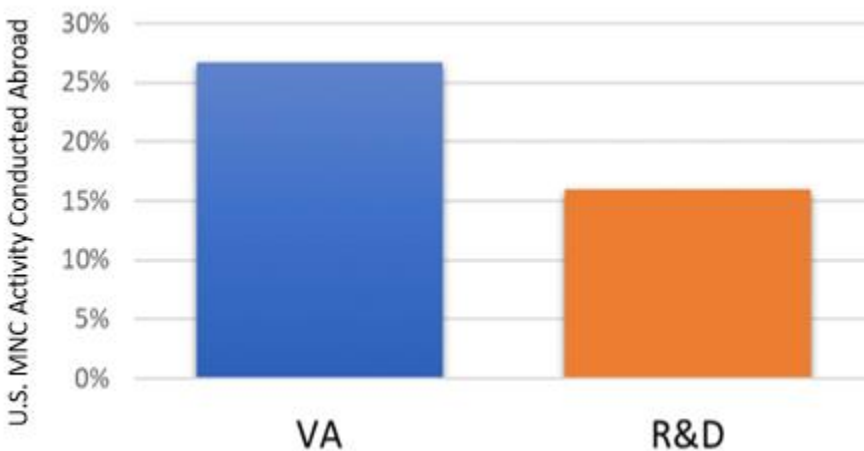


Figure 12 The percentage of US MNC Activity Conducted Abroad in 2017 (BEA)

The picture becomes even more clear when we take this one step more and consider how US MNCs in the manufacturing sector geographically distribute their value added and R&D activities relative to those in the non-manufacturing sector. Figure _ illustrates this point: US MNCs in the manufacturing sector do only 14% of their R&D activities abroad, while those in

the non-manufacturing sector do 20% of their R&D activities abroad, as of 2017. In contrast, they are much likely to have value-added abroad; 31% of manufacturing value added is at their foreign affiliates, while only 24% of non-manufacturing value added is at their foreign affiliates.

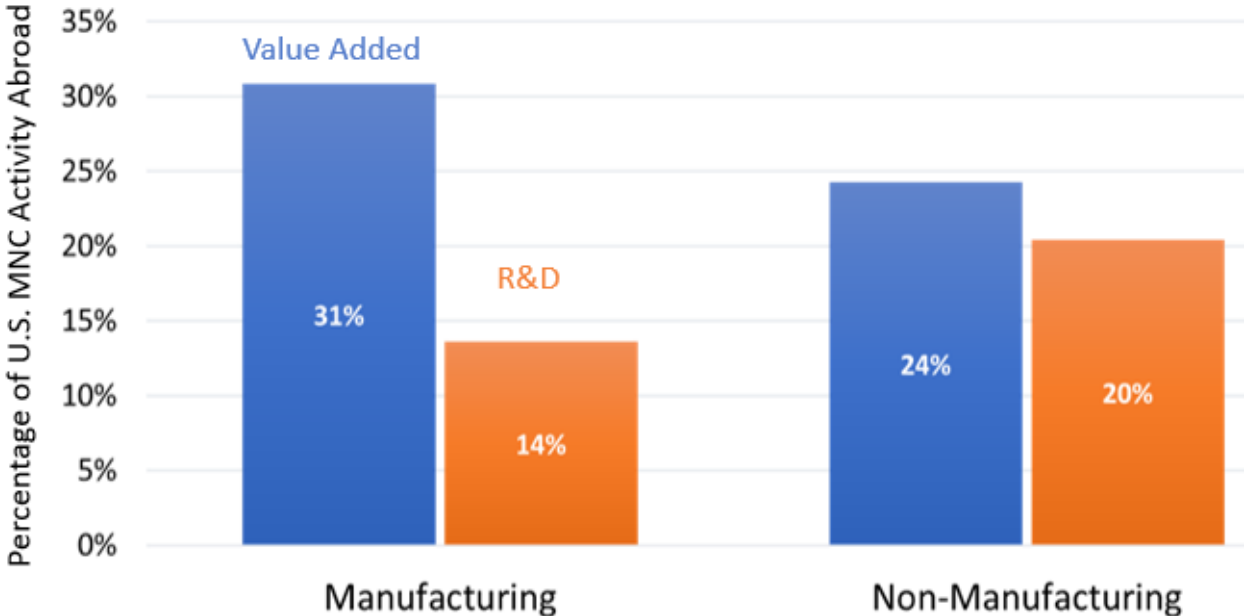


Figure 13 The percentage of US MNC Activity Conducted Abroad in 2017, by Sector (BEA)

The above data support our hypothesis and suggest that a significant part of the gap between manufacturing’s share of R&D spending and their realization in value added can be explained by recognizing that production is no longer constrained by national borders, while manufacturing R&D – in general terms – is more constrained.

5.2.4 R&D Increasingly Moving Abroad, But less so in manufacturing

R&D is increasingly moving abroad, especially in services and some manufacturing sectors. Although we document in section 6.2.3 that R&D is more concentrated at home than production, explaining the differences in manufacturing’s contribution to R&D vs VA within US domestic borders, it is important to recognize that (1) R&D is increasingly moving abroad, and (2) the concentration of R&D at home is only true for some sectors.

As shown below in Figure 14, there has been tremendous growth – in real terms – of foreign R&D. Since the late 1990s, the amount of R&D conducted overseas by US MNCs has grown nearly fourfold.

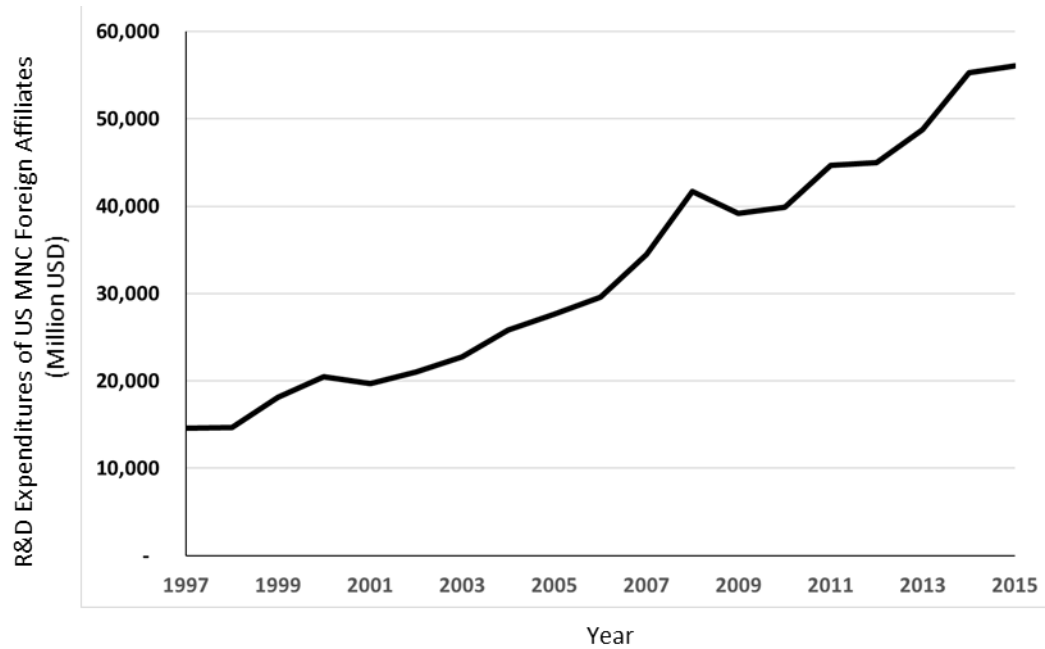


Figure 14 R&D expenditures of US MNC foreign affiliates, in millions USD (BEA)

Figure 15 and Figure 16 illustrate that the expansion abroad has largely been driven by non-manufacturing sectors. The services sector – and especially the professional, scientific, and technical services sector – in particular has dramatically increased the amount of R&D conducted at foreign affiliates rather than at the US parent company location. In contrast, at the aggregate level, the manufacturing industry as a whole has continued to keep the vast majority of their R&D at home.

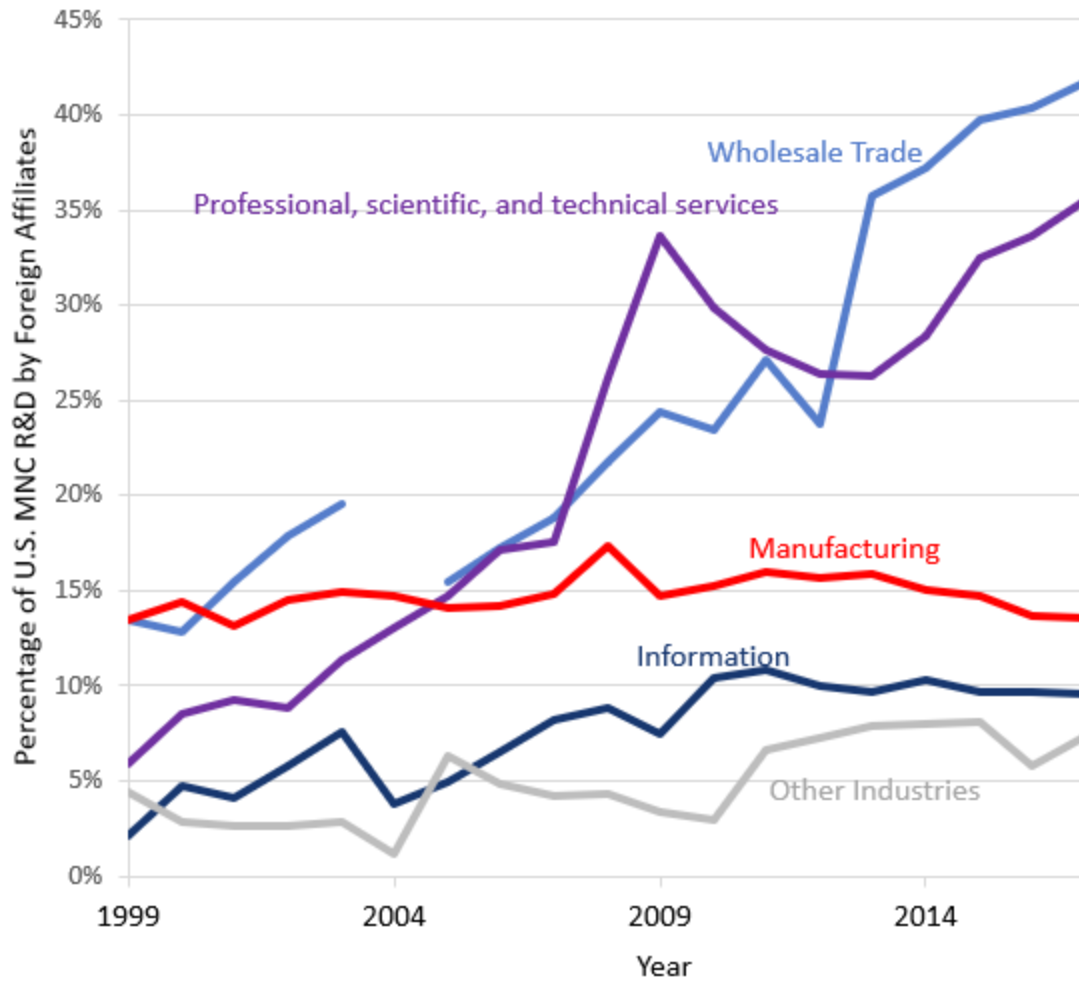


Figure 15 Percentage of R&D conducted at foreign affiliates, by sector (BEA)

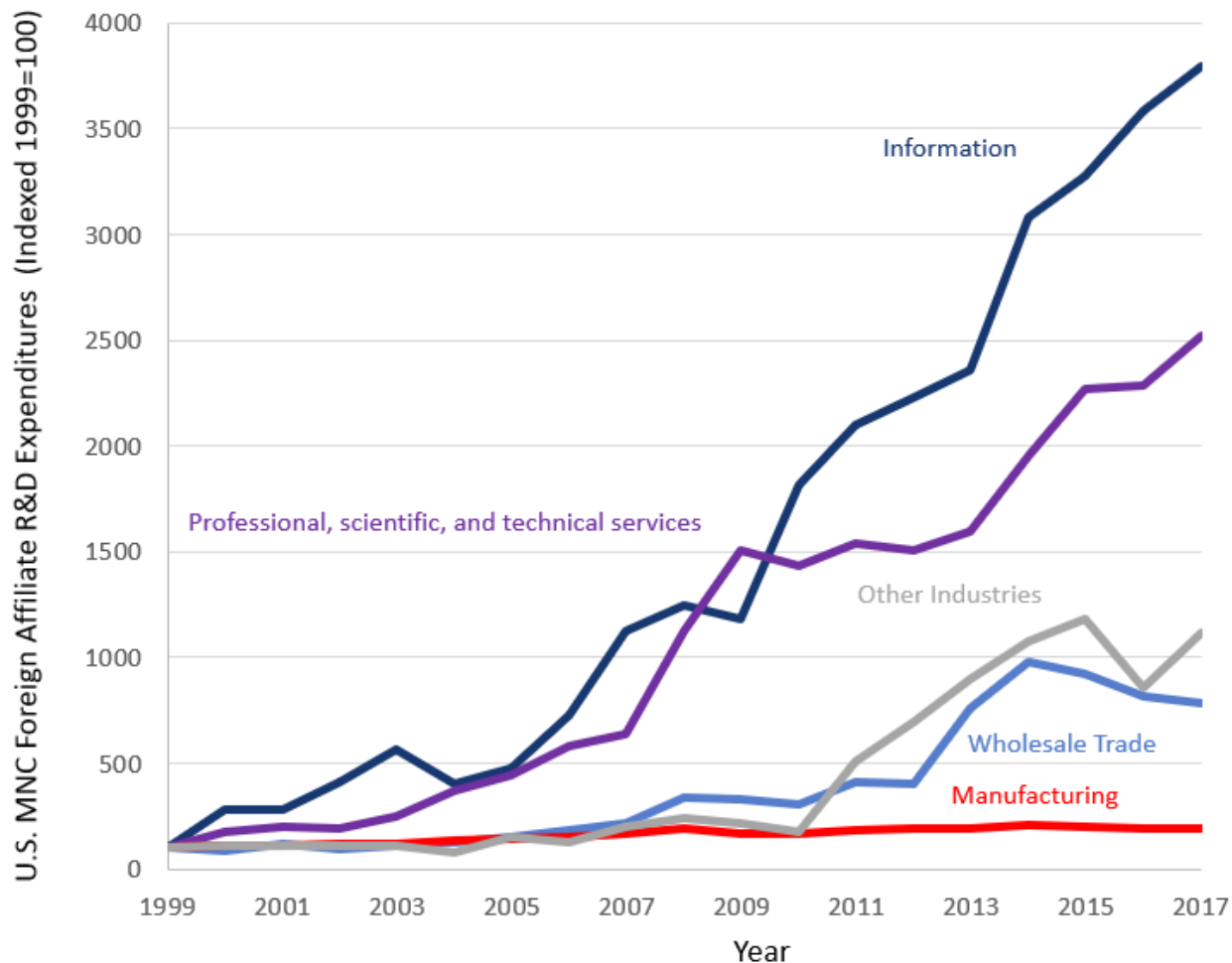


Figure 16 R&D Expenditures by US MNC Foreign Affiliates by Industry of Foreign Affiliate, Indexed (1999=100) (BEA)

6. Further Insights into the Puzzle: Manufacturing Sub-Sectoral Variations in the Concentration of Value Added, R&D Funding, Employment and Revenue

Today, the U.S. manufacturing sector is composed of industries that vary in the level of spending that they dedicate to research and development, with key industries representing dominant sources of current investment. The disproportionate role of manufacturing in R&D activity becomes starker when considering the top 5 manufacturing subsectors by R&D spending. These subsectors contributed 42% of U.S. industrial R&D Spending in 2015 (NSF 2018), despite representing only 18% of manufacturing value added and thus 2.1% of total value added in the economy (US Census Bureau 2018, BEA 2019). The role of these key subsectors offers further insight into the puzzle of outsized manufacturing R&D spending versus value added.

Manufacturing value added is not dominated by any core sector or sectors, nor are the top subsectors necessarily the largest by R&D spending. Figure 13 displays the share of overall manufacturing value added from both the top 5 manufacturing subsectors by value added and the top 5 manufacturing subsectors by R&D spending. We see that the top 5 manufacturing subsectors

by R&D have a total value added about a third lower than the top 5 subsectors by value added. Two subsectors, aerospace and pharmaceuticals, are both among the top 5 largest subsectors by MVA and R&D spending, but the remaining top subsectors by R&D spending are outweighed in value added by less R&D intensive subsectors.

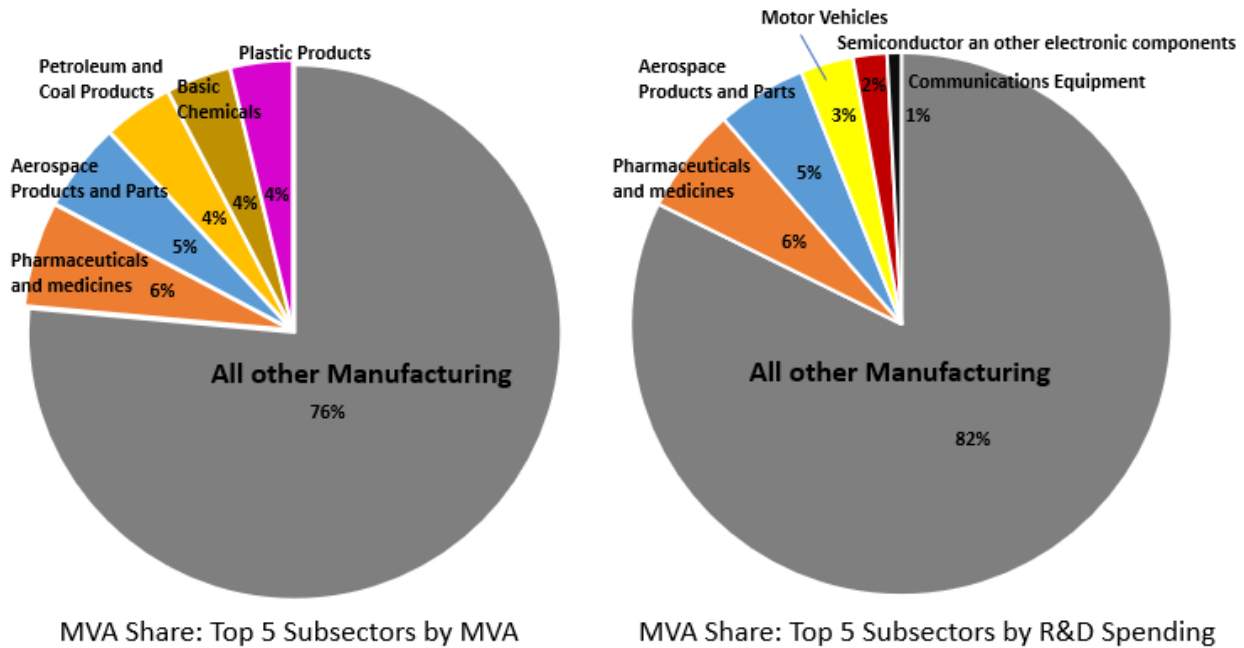
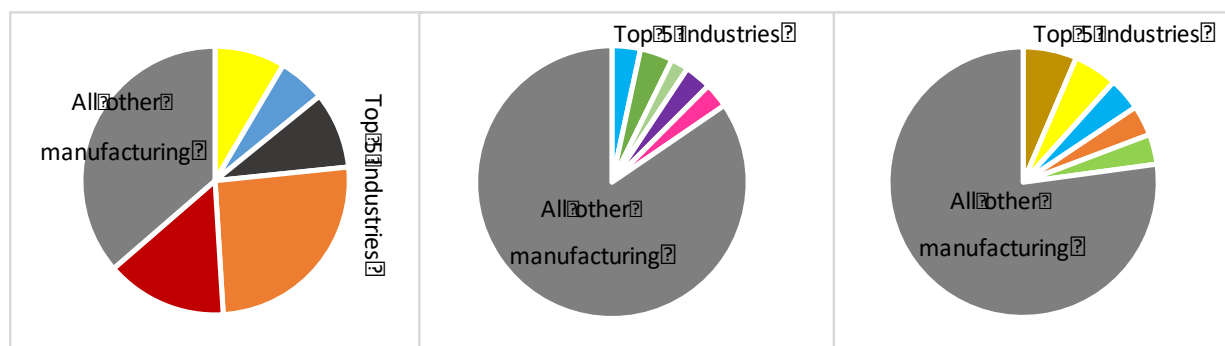


Figure 17 Share of Total Manufacturing Value Added by Subsector, 2015 (ASM)

Table 2 illustrates the concentration of R&D spending, Employment and Revenue within the manufacturing sector by 4-digit NAICS subsector: the pie charts are color-coded to match the top 5 firms in each measure for 2015, listed directly below the charts. As the table illustrates, the industries that provide the most funding for industrial R&D are not necessarily the largest employers or earners. Pharmaceuticals rank as the top R&D spending industry, animal slaughtering is the top employer, and petroleum refineries have the highest revenue. Only aerospace overlaps the top 5 ranking for all three indicators. However, the largest industries by revenue include three of the five largest by R&D funding (pharmaceutical, automobile, and aerospace) and two of the largest by employment (animal slaughtering and aerospace).

The pharmaceutical industry leads manufacturing R&D spending with 26% of the total, followed by semiconductors and electronic components with 15% of the total and communications, automobile and aerospace manufacturing contributing a cumulative 23%, for a total of 64% of Industry R&D funded by the top five industries. The gap between pharmaceuticals and medicines and the next largest subsector by R&D spending, semiconductors and other electronic components, is just over twice the gap between the second and third largest industry. Thus, not only are the largest five sectors by R&D spending disproportionately dominant, but the concentration continues to scale within the top five.

Table 2 The Concentration of R&D Spending, Employment and Revenue within Manufacturing (2015)



| Industry R&D Spending (\$billion) (NSF) | Industry Employment (thousands) (ASM) | Industry Revenue (\$billion) (ASM) |
|--|--|--|
| Pharmaceuticals and medicines (\$50.2B) | Animal slaughtering and processing (480k) | Petroleum refineries (\$388B) |
| Semiconductors and other electronic components (\$28.6B) | Aerospace product and parts (420k) | Automobile and light duty motor vehicle (\$318B) |
| Communications equipment (\$18.0B) | Printing (394k) ¹ | Aerospace product and parts (\$237B) |
| Automobile and light duty motor vehicle (\$16.6B) | Navigational, measuring, electromedical, and control instruments(365k) | Pharmaceutical and medicine manufacturing (\$220B) |
| Aerospace (\$11.1B) | Medical equipment and supplies (257k) | Animal slaughtering and processing (\$216B) |

Employment and revenue show a wider dispersion across manufacturing industries. The five largest manufacturing industries by revenue make up 23% of total manufacturing revenue, while the five industries with the highest employment represent 15% of total employment.

¹⁷ This industry comprises establishments primarily engaged in **printing** on apparel and textile products, paper, metal, glass, plastics, and other materials, except fabric (grey goods). The **printing** processes employed include, but are not limited to, lithographic, gravure, screen, flexographic, digital, and letterpress. (NAICS 2017)

While the pharmaceutical industry is a major source of R&D funding, it does not solely drive the disproportionate concentration of R&D funding among type funds: even without pharmaceuticals, the next four industries account for 38% of R&D spending by manufacturing, more than half again the concentration of employment or revenue among top five sectors and more than twice the concentration among the second through fifth place sectors.

The top five manufacturing industries by R&D funding are consistent from 1994¹⁸ to the latest NSF data by sector in 2015. Figure 18 illustrates that while the overall composition was consistent, the relative positions of top industries by R&D funding evolved over this period. The automotive industry, which ranked 4th for R&D funding in 2015, was the largest manufacturing funder of R&D from 1994 to 2003, with pharmaceuticals and medicines dominating from 2004 to 2015. While pharmaceuticals and semiconductors grew in R&D funding after 2004, aerospace, automotive and communications equipment manufacturing appeared to largely stagnate or decline throughout the period, except for modest growth in communications R&D funding after 2011. The relative composition of R&D funding in manufacturing has shifted over the period 2004-2015 period, with the bottom three industries remaining fairly close to each other in level of funding and a growing gap between both the top and bottom three and between pharmaceuticals and semiconductors.

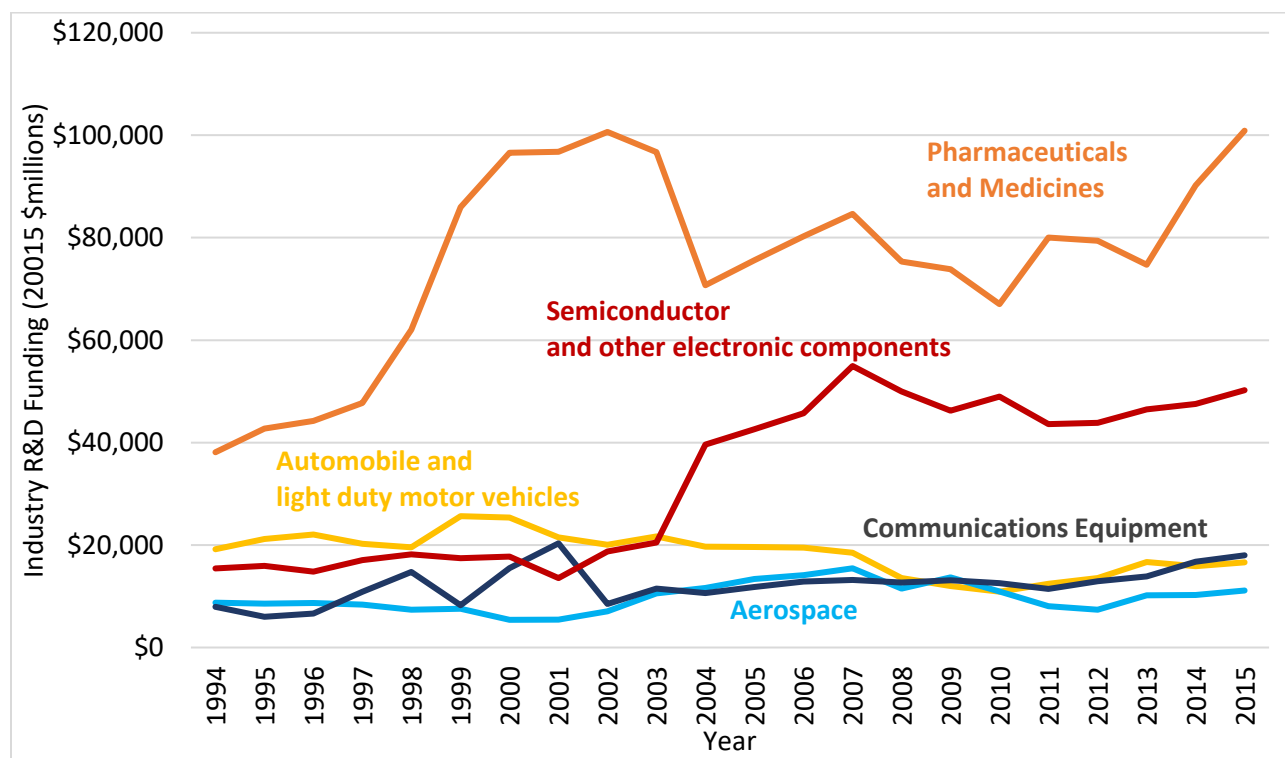


Figure 18 Industrial R&D Funding by Top 5 R&D Funders in Manufacturing, 1994-2015

¹⁸ The NSF annual reports on “Research and Development in Industry” including annual data extending back to 1982, but classification shifts from the 1993 to 1994 reports limit comparisons before 1994: the composition of the top 5 sectors may have changed prior to 1994, but comparison is infeasible before and after the reclassifications.

7. Sub-Sectoral Nuances in the Offshore Realization of Manufacturing R&D Returns

7.1 Globalization of MVA: R&D Subsector Story

Although on aggregate US MNCs in the manufacturing industry concentrate their R&D activity in the US, Figure 19 below demonstrates the degree to which this varies. Industries like petroleum conduct almost no R&D abroad, while textiles and printing conduct almost a third of their R&D at their foreign affiliates.

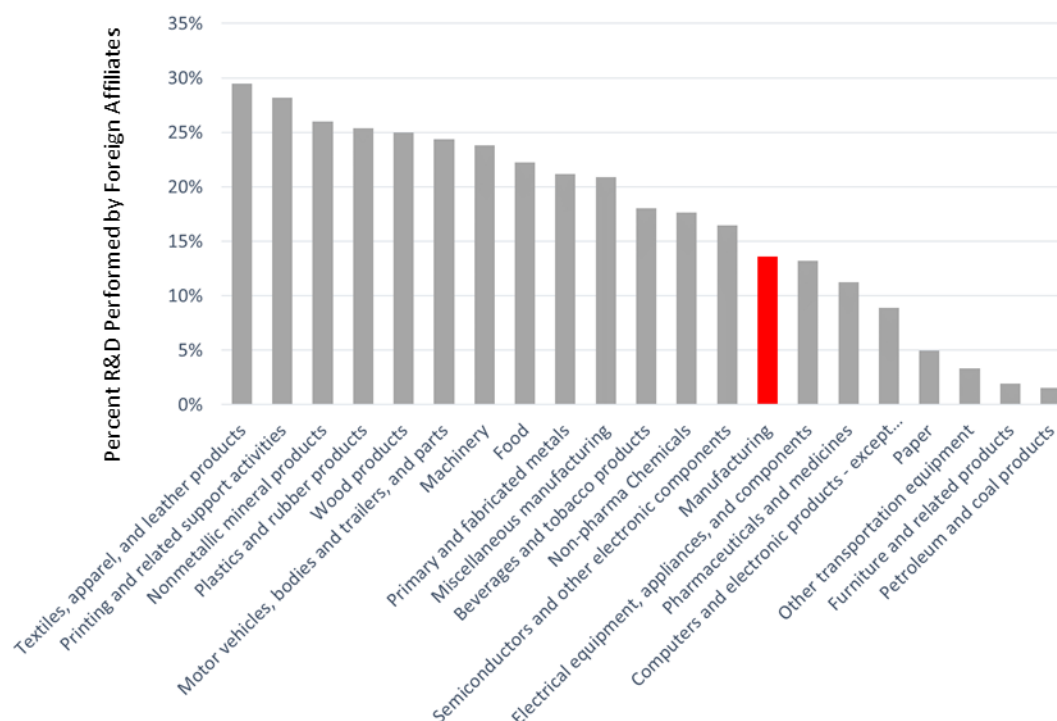


Figure 19 Percentage of R&D performed at US MNCs foreign affiliates in 2017 (BEA)

In short, while US MNCs continue to concentrate their R&D activity predominately within the United States, even as they have expanded production overseas, R&D is increasingly a global activity – particularly in the services sector and some manufacturing sectors.

7.2 Globalization of MVA: Labor subsector story

The realization of MVA returns abroad by key manufacturing subsectors by R&D spending also aligns with differences in the educational demand of those subsectors relative to the rest of manufacturing. While the overall manufacturing distribution of employment and wages is characterized by higher employment and wages for non-college educated workers (see section 4), we show in Figure 20 that the largest manufacturing subsectors by R&D spending (left) tend to skew less toward high school level employees than the largest subsectors by employment (right). The figure reports on some subsectors at higher levels of aggregation than the NSF data due to imperfections in data cross walking between the IPUMs database and NAICs classification, but the aggregation occurs across sectors with similar R&D spending and offshoring profiles (e.g. motor vehicles and aerospace).

Our findings suggest that the role of manufacturing in R&D spending may be relatively decoupled from the sector's overall labor profile, so that value added gains from R&D may not translate directly into value added or employment growth for high-school intensive subsectors. Not only do the subsectors driving manufacturing R&D spending overall employ relatively fewer high school level employees, those subsectors which have offshored the most (e.g. electrical and communications equipment) appear to skew furthest away from high school level employment. The subsectors realizing MVA returns offshore have a more highly educated domestic employment profile than do subsectors with lower offshoring and either low R&D or high R&D spending.

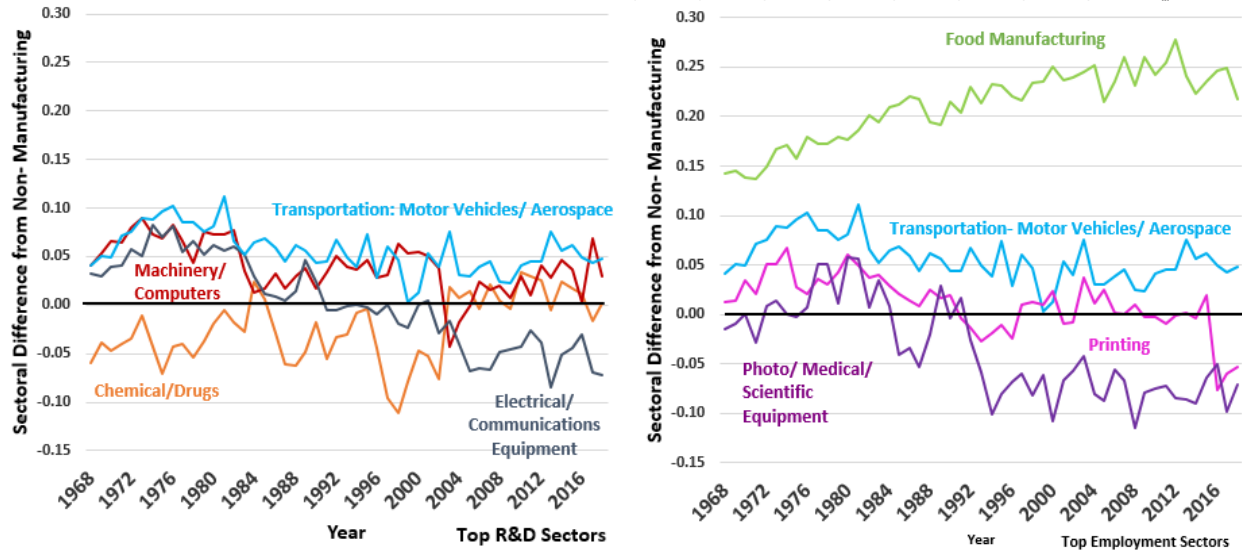


Figure 20 Manufacturing Sub-sectoral Differences from Share of High-School Level Employees in Non-Manufacturing 2015 [Top 5 R&D Spending Subsectors (left) and Top 5 Employment Subsectors (right)] (IPUMS – CPS ASEC microdata 1968- 2018)

8. Discussion: Potential Relationships between Manufacturing Location, Innovation, and Labor Outcomes

8.1 The Potential Relationship between Manufacturing and Innovation:

Economic theory suggests that shifts in manufacturing away from a nation may hurt wages there, but global innovation and productivity gains will not suffer (Samuelson, 2004). However, recent work suggests that, at least in certain contexts, moving the location of manufacturing can alter whether and which next generation products are profitable (Fuchs et al 2010; Fuchs et al 2011). Production characteristics (wages; yields; downtimes; organization of production) can differ greatly across nations (especially developed and developing ones). In two cases—automobile bodies and high-end optoelectronic components for communications—when U.S. firms shifted production to developing East Asia, differences in these production characteristics meant that products developed in the U.S. based on the most advanced technologies were no longer immediately profitable. The overseas firms stopped producing these products and, in optoelectronics, also stopped innovation (measured as patenting) in the most advanced products in all of their locations overseas and in the United States (Fuchs and Kirchain 2010; Yang, Nugent, and Fuchs 2014).

Additional recent work has also implied that a relationship can exist between foreign

competition and reductions in domestic innovation. Autor et al (2019) find that foreign competition (in the form of import substitution) reduces U.S. innovation. One potential mechanism behind this finding could be cost reductions giving a longer life to older generation products, by raising the barrier for next generation products to be profitable. However, it is not clear what if any relationship exists in this case between foreign competition and foreign innovation.

More research is needed on the relationship between manufacturing location and innovation, and how that may differ by technological and industrial context. Increased distance, electronic dependence, time zone changes, and national differences all can reduce knowledge flows (Gibson and Gibbs 2006; Cummings, 2009). In certain contexts—particularly, unfamiliar, unstructured problems—problem solving can require physically present experts to recognize embedded clues, exploit specialized tools, and find and interpret relevant information (Tyre and von Hippel 1997). Yang, Nugent, and Fuchs (2014) find that offshoring by U.S. firms from the U.S. to developing East Asia (including producers in Taiwan, Singapore, Malaysia, and Shenzhen) is associated with fewer patents in the most advanced products by the firms, but more patents in other technological areas likely related to general production. Branstetter et al (2018), exploiting a policy shock in Taiwan that allowed Taiwan’s electronic and IT firms to legally offshore their manufacturing to China, find that offshoring has a negative impact on firm innovation as measured by patents. They write, “At least one plausible interpretation of our negative coefficient is that offshoring and the innovation it displaces are alternative means to the same end. If many of the foregone patents were for process-oriented, cost-reducing innovations, then Taiwanese firms may have been able to realize cost reductions through offshoring more cost-effectively than if they had tried to achieve the same degree of cost reductions through process-oriented R&D.” However, they also find suggestive evidence that Taiwanese firms changed their research portfolio after offshoring towards more product innovation and away from process innovation. As the authors note, “This reallocation [toward more product innovation] could have been welfare-enhancing, even if it did not expand the total number of patents.”

Fuchs (2014) suggests that three conditions shape the impact of manufacturing location on global technology development: (i) the number of manufacturing facilities that a firm can sustain (potentially influenced by the ratio of their minimum efficient plant size to the size of the market and their share thereof); (ii) the location of product and process design expertise and whether the designers need to be physically present at the production line; and (iii) the importance, security, and enforcement of intellectual property rights. These conditions particularly affect early-stage high technology start-ups involving early-stage advanced materials and processes (Fuchs 2014). Challenges separating design from manufacturing are common for early-stage products in industries such as semiconductors (Lecuyer 2006), pharmaceuticals (Pisano 2000), and additive manufacturing (Bonnin-Roca 2017b) in which product innovations are fundamentally linked to advances in process. In these contexts, a lack of codified knowledge about the relationships between inputs and outputs and the underlying science supporting outcomes, leads to low yields, and can make production more of an “art” than a science in the early stages of new products (Fuchs and Kirchain 2010, Bohn 2005, Bonnin-Roca 2017b). A small market compared with the production output required to take advantage of economies of scale is also common for early-stage high technology start-ups, forcing them to choose just one manufacturing location. In contrast, firms that can sustain multiple manufacturing facilities and don’t struggle with separating design from production could potentially leverage location-based

differences in production characteristics to diversify their product development portfolio, and potentially increase their innovation.

Further, national differences in consumer preferences may also have a role in incentives for innovation. Today approximately one third of conventional vehicles are produced in China, but more than half of electric vehicles are produced in China. While the conventional vehicles are produced predominantly by joint ventures with multinational firms, the electric vehicles are produced predominantly by independent domestic Chinese firms. Helveston et al (2015) find that, all else being equal, consumers in China are more willing to pay for electric vehicles than consumers in the U.S. Local and national policy can then further shift the playing field. Helveston et al (2019) finds a combination of local and national policies in China associated with significant regional experimentation in electric vehicle technologies by independent domestic manufacturers. Specifically, joint venture requirements may be creating disincentives for multinational or their Chinese joint venture counterparts to undertake electric vehicle production or innovation in China, leaving open – with combination of supportive resources and protectionism from regional governments – for independent domestic Chinese firms to move into the Chinese electric vehicle market (Helveston et al 2019).

8.2 Technology change in manufacturing and labor outcomes

Recent research has investigated how employment and labor skill demands in manufacturing, and industry more broadly, are associated with globalization, technology change, changes in what is being manufactured, and other factors. The adoption of new technologies in manufacturing has the potential to alter the demand for labor, including biases toward certain types of skill (Card and Dinardo 2002). There is a documented polarization of skill demand (measured as education or wage percentile) in the U.S. economy, which Autor and Dorn (2013) attribute to a combination of sectoral shifts in demand toward low-skill service work and increases in automation (capital intensity). Research suggests that automation (measured as increases in capital to labor share) shifts manufacturing labor demand away from middle income jobs, as capital substitutes for labor in routine tasks and (Autor, Levy and Murnane 2003, Autor and Dorn 2013). Industrial robots in particular may reduce employment and wages overall (Acemoglu and Restrepo 2017). Contributing at the high end of the observed polarization, technological shifts in production toward continuous processing may also drive an increase in the demand for worker skill (Goldin and Katz 1997), shifting from line operators toward labor involved in equipment support. Some technology change may shift the skill requirements of an occupation (e.g. more operators pressing buttons and monitoring equipment than hand-assembling parts) while keeping the demand for labor within that occupation constant; other technology change may shift skill requirements such as to shift the demand for occupations (e.g. fewer operators and more engineers). In the context of optoelectronic semiconductors, Bartel et al. (2004, 2007) suggest that information technology adoption in production facilities, coincides with increased skill requirements for machine operators, particularly in technical and problem-solving dimensions. In contrast, Combemale et al. (2018) find that automation polarizes the demand for skill within manufacturing operator occupations, eliminating demand for middle-skilled tasks while shifting demand toward low and high skill tasks. Relatedly, Combemale et al (2018) find that parts consolidation drives a convergence in skill demand toward middle skills (again in the context of optoelectronic semiconductors). Of potential policy interest, Combemale et al.'s (2018) work finds that competing technologies with seemingly comparable production cost outcomes can be associated with different outcomes for labor and skill demand.

9. Conclusions, Potential Policy Implications, and Future Work

Though its global share of value added and share of domestic employment and domestic product have been in decline, U.S. manufacturing remains a disproportionate source of value creation within the U.S. economy relative to its share of employment and, while slightly declining, still a majority source of private R&D spending.

Manufacturing is an outsized employer of non-college educated workers. Analyzing the demographic make-up of the manufacturing labor force reveals several stylized facts: While the proportion of participants who are higher educated has been increasing, the manufacturing workforce has consistently been less educated than the overall workforce (by a relatively stable 6-10 percentage points). However, there is significant heterogeneity in the labor force across subsectors in manufacturing with food manufacturing featuring the highest proportion of less educated workers. The proportion of the manufacturing labor force earning less than \$10,000 (2017 dollars) is consistently lower than that of the non-manufacturing labor force, with a higher proportion of workers whose earnings fall in the categories between \$10,000 and \$250,000 (all 2017 dollars).

While private equity and venture capital (VC) funding sources have drastically expanded over the last decade, the proportion of deals by count (2%) and monetary volume (3%) aimed at manufacturing industries is comparatively quite small. This lower investment in manufacturing is perhaps surprising given that Lerner and Kortum (2000) find that VC in manufacturing is more productive (measured by patents per dollar) than corporate R&D.

U.S. industrial R&D funding is unusually concentrated in manufacturing compared with U.S. manufacturing employment, revenue and value added. This disproportionate concentration in R&D compared with the other measures is in part driven by the offshoring of manufacturing facilities to other nations, and in particular China, without equivalently large offshoring of manufacturing R&D. The U.S. manufacturing sector's dominant role in private funding of R&D is driven by five industries (aerospace, automobile, pharmaceuticals, semiconductors and telecommunications). The research intensiveness of manufacturing contrasts with the information sector's orientation toward development funding and high levels of venture capital support. The capital intensity of manufacturing (Levinson 2013; Pierce and Schott 2016) might contribute to this pattern and, in turn, encourage participation of large firms, who might be better positioned to capture the returns of their basic research efforts (Cohen and Klepper 1996).

While patenting of innovations can allow appropriation of R&D, industry level surveys indicate it is only one mechanism used by manufacturing firms, and often not the dominant one (Levin et al. 1987, Cohen et al. 2000, Arora et al. 2015). Recent data by Arora et al. (2015), notes the increased use of external sources of innovation for product inventions, which might increase patenting in manufacturing. Branstetter, Li, and Veloso (2014) document an increase in the global innovative activity by U.S. multinational firms (as measured by patents); however, the largest fraction of patents in emerging economies is in services while developed countries continue to do a disproportionate amount of manufacturing patenting. Patenting by developing countries with high manufacturing value added, in particular China, is slowly growing in some manufacturing subsectors but not equally across all.

Along with other factors, the adoption of new technologies in manufacturing over time is contributing to changes in the nature and demand for labor, including biases toward certain types of skill (Card and Dinardo 2002). Further research will be necessary to determine the relative

contribution of offshoring, import competition, and technology change to observed economy-wide polarization in wages and education (Autor and Dorn 2013), and how different technologies may lead to different labor outcomes (Combemale et al. 2019).

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Appendices:

Appendix A: The Share of Manufacturing in U.S. Gross Value Added and the Share of the U.S. in Global Manufacturing and Gross Value Added

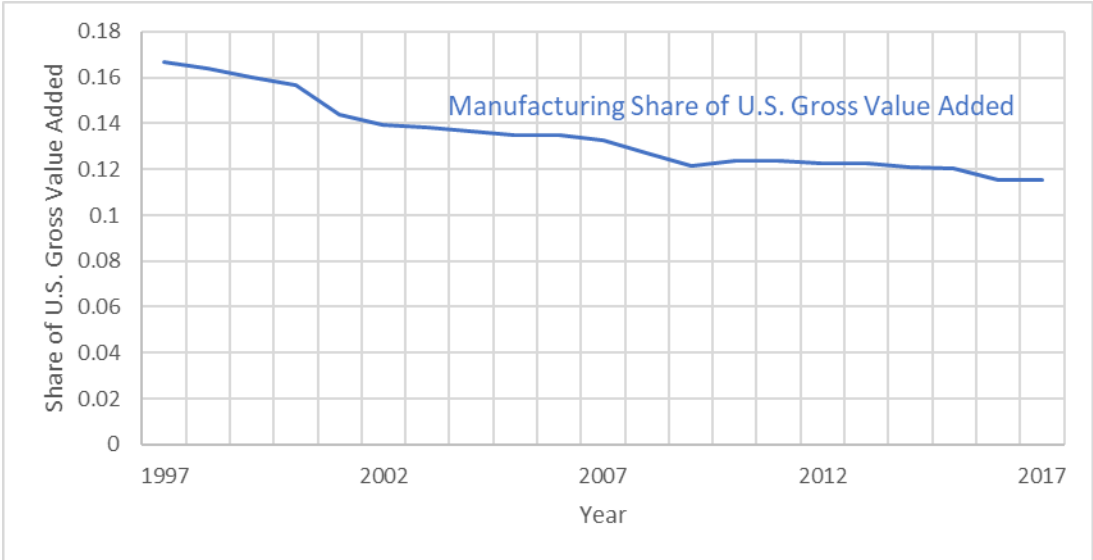


Figure A.1 Manufacturing Share of U.S. Gross Value Added 1997-2017

Figure A.1 illustrates the continually declining share of U.S. gross value added from manufacturing over the twenty years from 1997 to 2017. While U.S. MVA rose in real terms over the same period, its relative contribution to the economy shrank. The U.S. share of global MVA and Gross Value Added both declined from 1997 to 2017: the decline of manufacturing as a share of the U.S. economy is mirrored in the steeper decline of the U.S. share of global MVA, relative to world GVA.

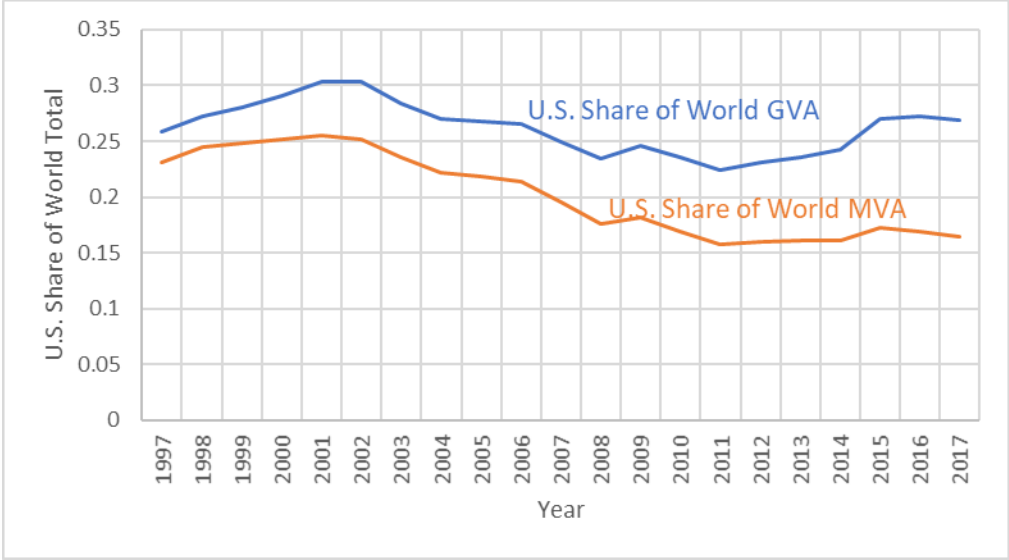


Figure A.2 U.S. Share of World MVA and GVA 1997-2017

Appendix B: Additional Visualizations of the Manufacturing Labor Force

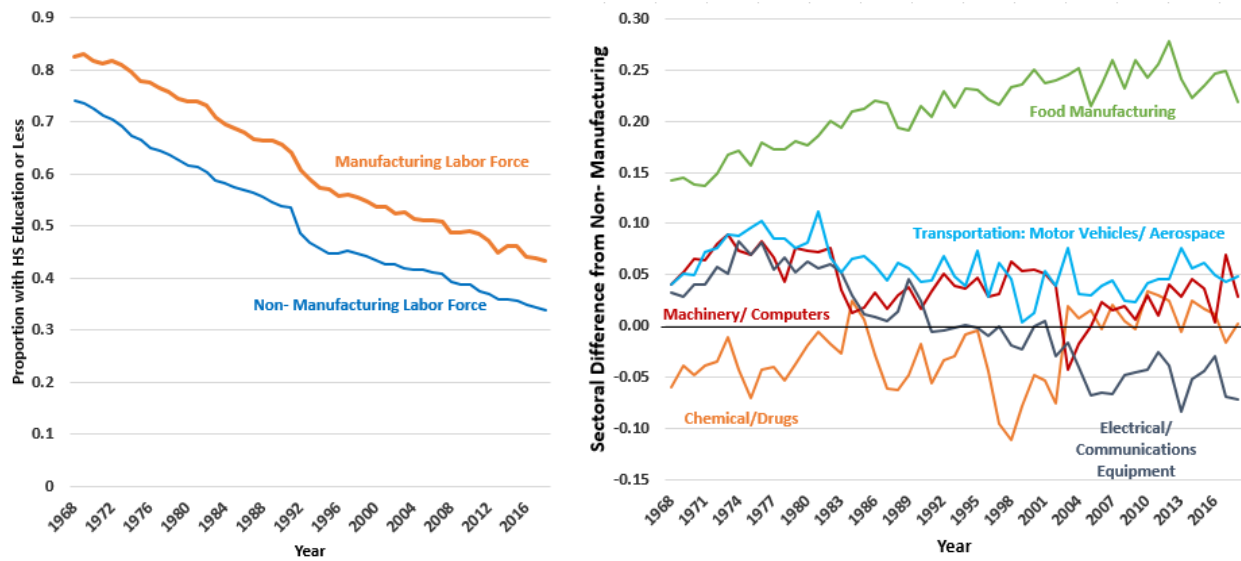


Figure B.1 Select manufacturing subsectors difference from non-manufacturing's educational attainment IPUMS- CPS ASEC microdata (1968- 2018) IPUMS – CPS ASEC microdata 1968-2018¹⁹

Subsector analysis reveals heterogeneity among leading R&D and employment subsectors. Figure B.1 displays the difference in educational attainment of a few selected subsectors relative to the non-manufacturing sector. These subsectors include the top 5 subsectors by private R&D spending and the top 2 subsectors by employment in 2015. As can be seen, the manufacturing subsector that contributes the most to employment – the food manufacturing subsector (green line) – has on average a ten percent higher proportion of employees with HS education or less than non-manufacturing sectors. It also had an approximately 12 percentage higher proportion of employees with HS education or less than the overall workforce proportion in the 1970s, with that gap widening in the recent decade to around 22 percentage points. Other subsectors with a relatively large proportion of HS educated or less workers include apparel, textile, furniture, leather, and lumber manufacturing. In contrast, the top R&D spending manufacturing sub-sectors have larger proportions of their labor force who are higher educated: consider the chemical/drug subsector and the communications subsector, both contain a larger proportion of higher educated workers than non-manufacturing sectors.

¹⁹ Note: the NAICS imperfectly crosswalks to the Industry Codes in the IPUMS-CPS data, given the level of aggregation for our analysis aerospace and automotive subsectors were combined as were navigating instruments and medical equipment

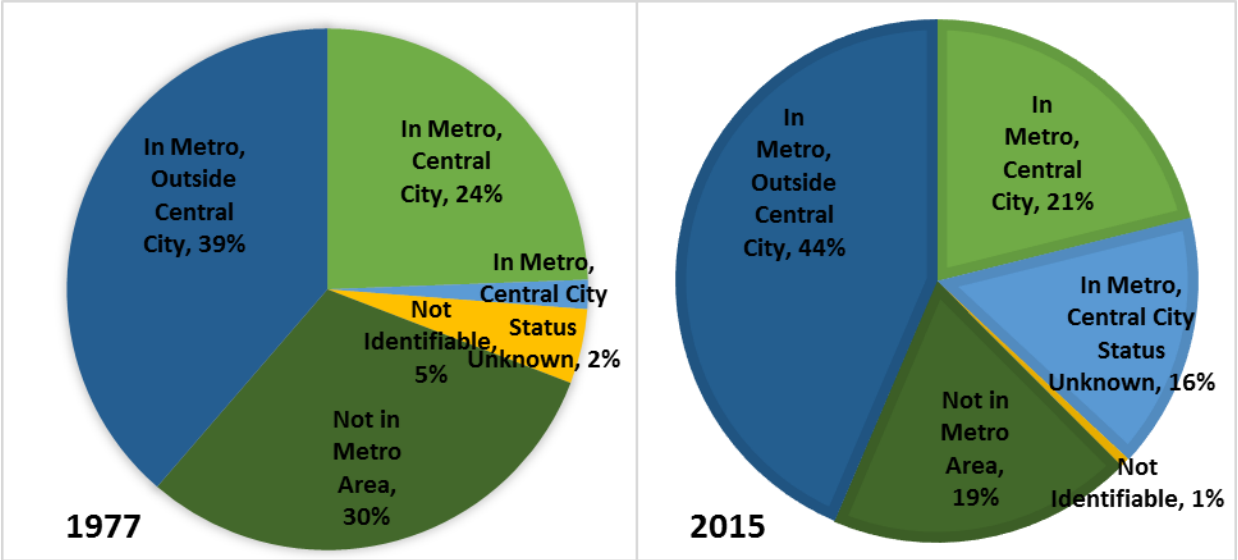


Figure B.2: Geographic location of the manufacturing labor force, IPUMS- CPS ASEC Microdata (1977 and 2015)

It is well-known that given manufacturing’s floor space requirements and the higher cost of building space per square foot in metro areas and their central cities, manufacturing firms are often located outside of central cities/ metropolitan statistical areas. Figure B.2 exhibits the manufacturing labor force’s geographic location.

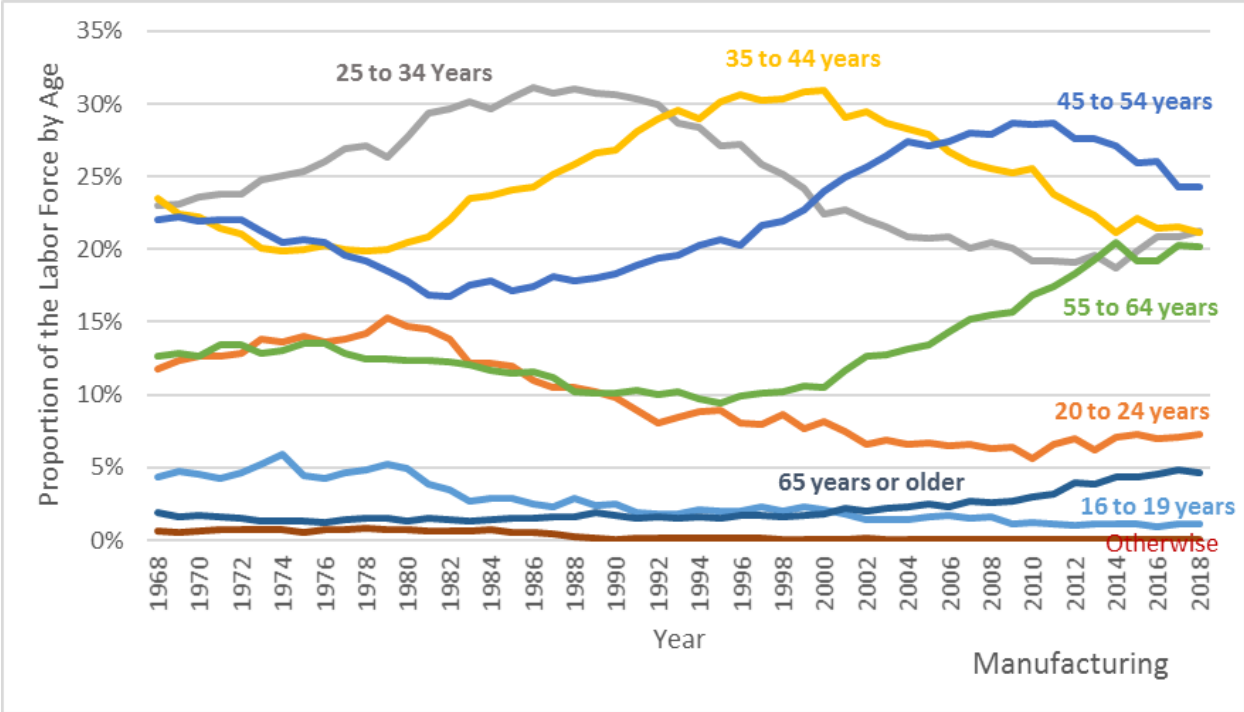


Figure B.3 Manufacturing Labor Force Age Distributions, IPUMS- CPS ASEC microdata (1968- 2018)

The age distribution of the manufacturing labor force is quite similar to the non-manufacturing workforce for prime aged workers (ages 25 to 64). Across time, the manufacturing labor force consistently has a lower proportion of participants age 16-19 and 20-24 and consistently has a larger proportion of participants age 25-64 relative to the non-manufacturing labor force. As can be seen in Figure B.3, within manufacturing, the proportion of labor force participants aged 16-19 and 20-24 have fallen across time. Meanwhile, the largest mass of the labor force has been increasing in age across time: the largest proportions of workers are aged 25-34 in the 1980s, aged 35-44 in 1990s, and aged 45-54 in the mid-2000s. Finally, the proportion of participants aged 65 and above in manufacturing is consistently lower relative to the non-manufacturing labor force although it has increased slightly over the last four decades.

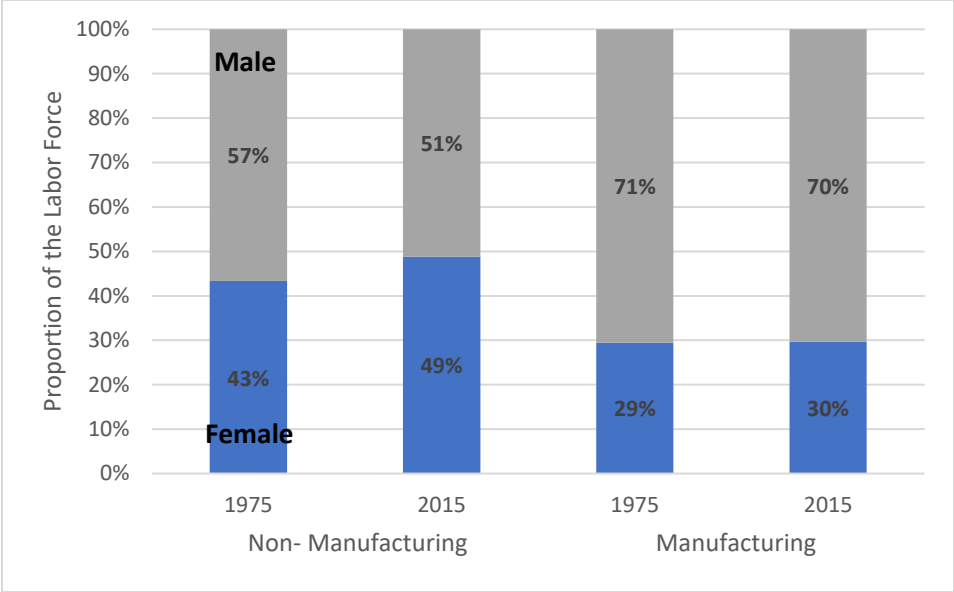


Figure B.4 Gender Composition of the Non- Manufacturing and Manufacturing Labor Force, IPUMS- CPS ASEC Microdata (snapshots of 1975 and 2015)

Figure B.4 shows the gender composition of the manufacturing and non-manufacturing labor force in 1975 and 2015. Across both non-manufacturing and manufacturing sectors, the majority of the labor force is comprised of male workers; however, manufacturing sectors have proportionately fewer female workers and thus more male workers. Across time- the gap in the labor force composition of manufacturing is quite stagnant whereas non-manufacturing subsectors have made progress toward parity.

Appendix C: Additional Private Equity/ Venture Capital Data Visualizations

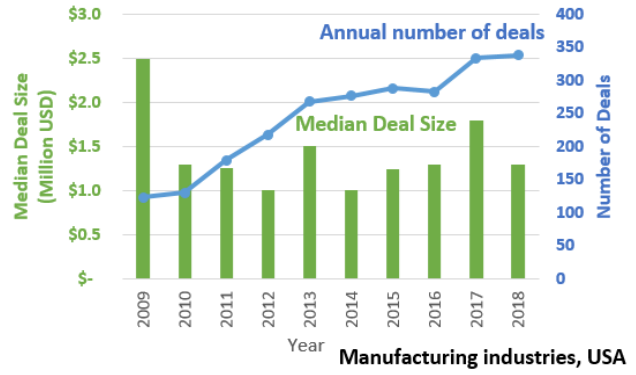
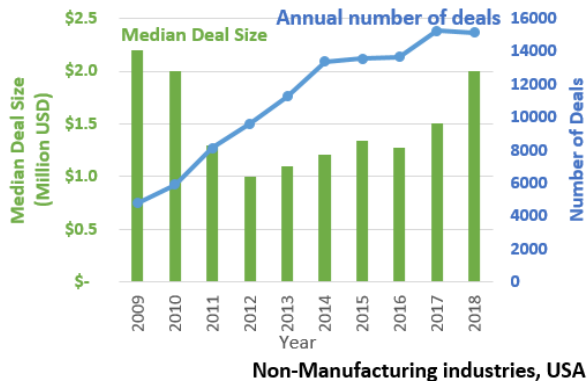


Figure C.1 PE/ VC in Non-Manufacturing Industries (left) and PE/VC in Manufacturing Industries (right), each with median deal size, data retrieved from CB Insights June 2019

As seen in Figure C.2, the U.S.'s percentage of global VC/PE deals in manufacturing dominate that of China, Germany, and Japan, however, PE/ VC to manufacturing industries in China and Germany feature a higher median and mean deal size. Figure C.3 features a similar visualization of the global distribution of non-manufacturing deals. Note that the global geographic dispersion of PE/ VC deals is quite similar between both manufacturing and non-manufacturing industries.

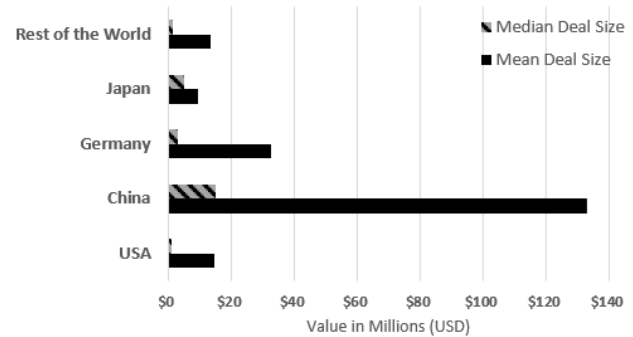
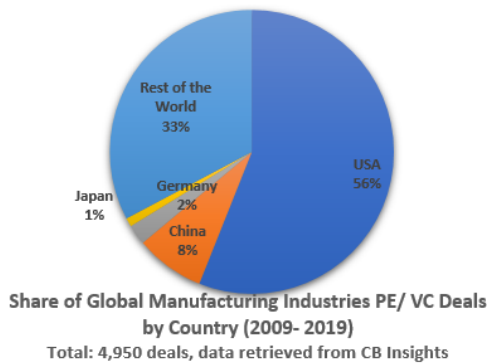


Figure C.221 Comparison of Global Manufacturing Industries PE/ VC, Inclusive of Top Four Countries by MVA; share of total manufacturing deals (left), median and mean deal size by geography (right). Data retrieved from CB Insights June 2019.

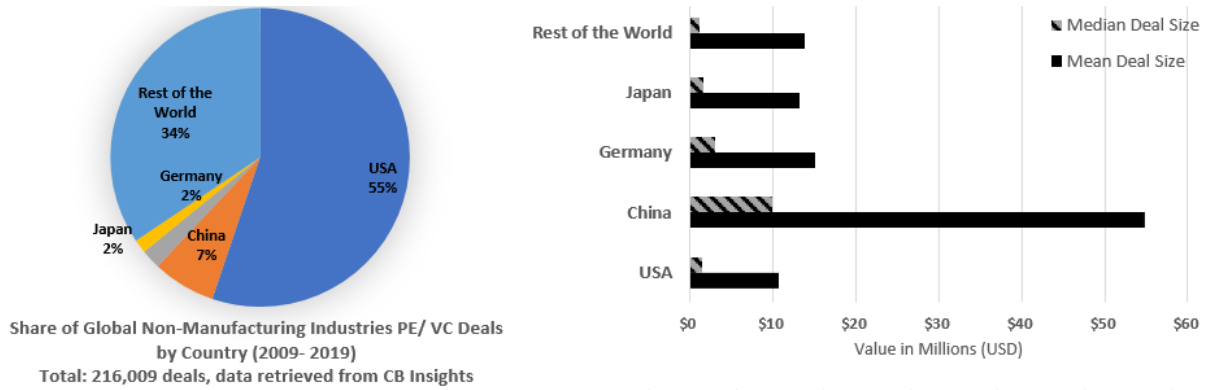


Figure C.3 Comparison of Global Non-Manufacturing Industries PE/VC, Inclusive of Top Four Countries by MVA; country share of total non-manufacturing deals (left), median and mean deal size by geography (right). Data retrieved from CB Insights June 2019

Appendix D: “Public VC:” Data Visualization of SBIR and STTR Awards

The combined SBIR and STTR award counts, annual total award amounts, and distribution of awards by funding agency are exhibited in Figure D.1 (data from SBIR.gov)²⁰. Interestingly a majority of the awards have been given by two agencies: the Department of Defense and Health and Human Services.

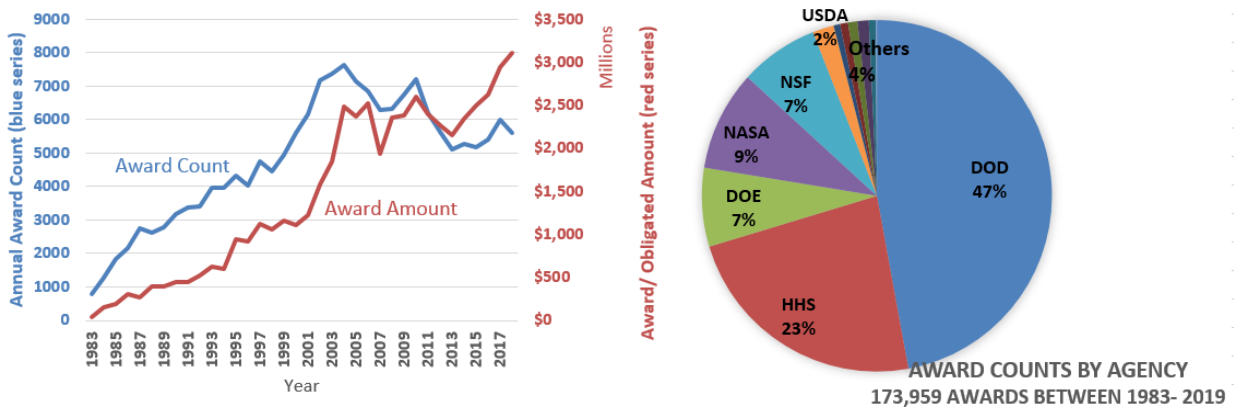


Figure D.1 Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs Award Counts and Total Award Value by Year (left) and Distribution of Awards Given From Federal Agencies (right), 1983-2019, data retrieved from SBIR.Gov July 2019

Appendix E: Patenting Figure Reproductions

²⁰ “Other” agencies include DHS, ED, EPA, DOT, DOI, and NRC

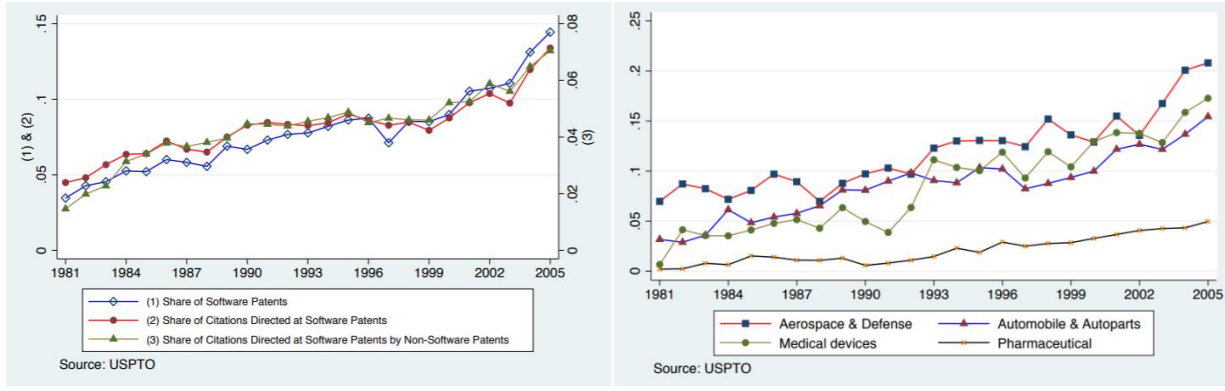
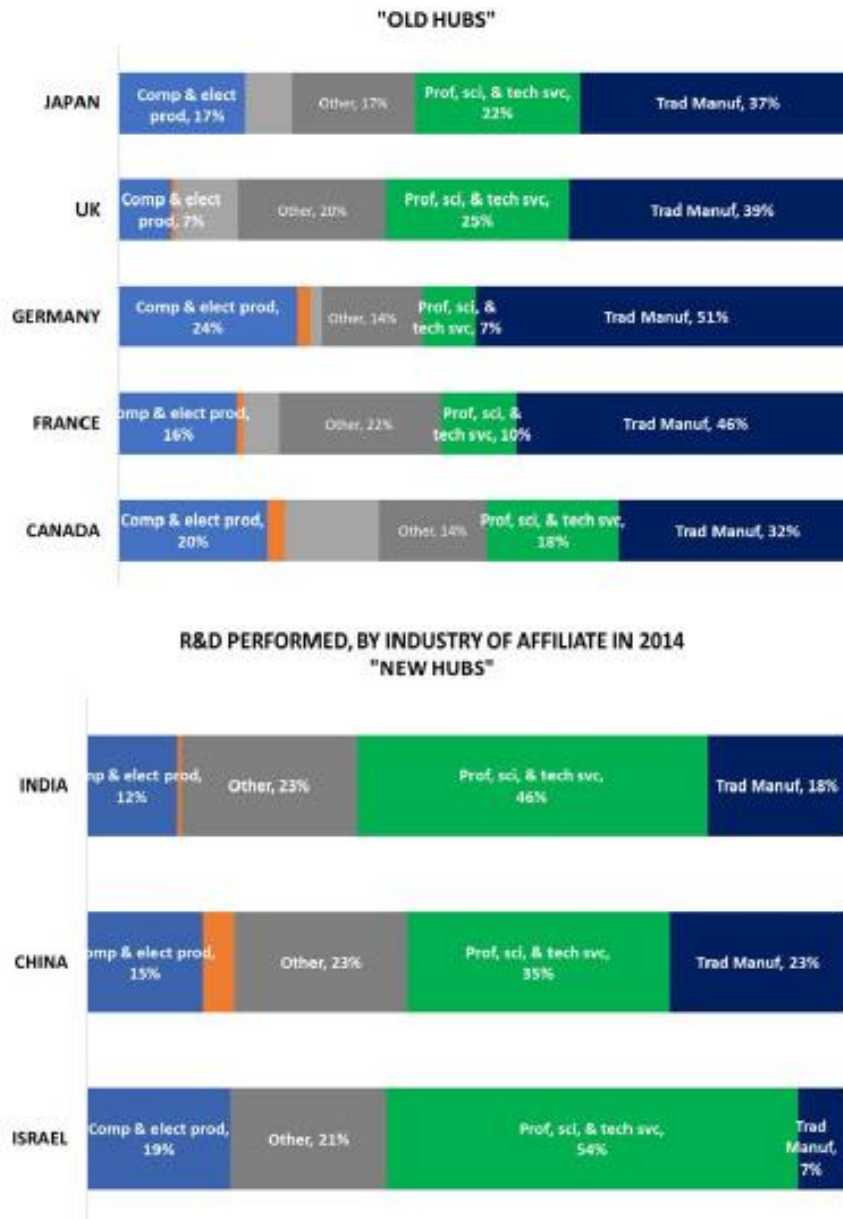


Figure E.1 Reproductions of Figure 1: Software Intensity of Patent Portfolios of Firms Active in Four Manufacturing Industries, (left) and Figure E.1: Share of Software Patents by Industry (Grant years 1981-2005) (right) Source: Branstetter et al. (2016) In both cases data is from the USPTO.



Notes: "Trad Manuf" refers to Chemical, Food, Machinery, Primary & Fabricated Metals, Transportation Equipment. Other includes mining, trade, and other. "Prof, Sci, & tech svc" is Professional, scientific, and technical services. "Comp & elect prod" is computer and electronics products manufacturing. The orange shade is for electrical equipment, appliances, and components manufacturing. The light grey is for information. The graphs illustrate that the specialization of "new hubs" like India, China, and Israel look very different from the specialization of "old hubs" like Japan, the UK, Canada, France, and Germany. Source is BEA public data.

Figure E.2 Old and New Research & Development Hubs, as Characterized by Branstetter, Glennon, and Jensen (2018b)'s Figure 3, reproduced here

Appendix F: Firm Counts and Firm Size Distribution

The total number of firms (irrespective of industry) in the U.S. have ranged from over 6.05 million firms in 2007 to 5.96 million firms in 2016, featuring a trough closely coincident with the business cycle: declining to 5.68 million firms in 2011, before increasing again (U.S. Census Bureau's Statistics U.S. Businesses Survey (2007 to 2016), see Figure F.1. The proportion of manufacturing firms relative to the total number of firms' averages ~4.5% between 2007 and 2016 and has featured a slight decline in recent years, attributable to the lack of a sustained expansion in manufacturing firm counts relative to non-manufacturing firm counts following the Great Recession. The proportion of information sector firms of all firms has been relatively stable at ~1.2% over the same time period.

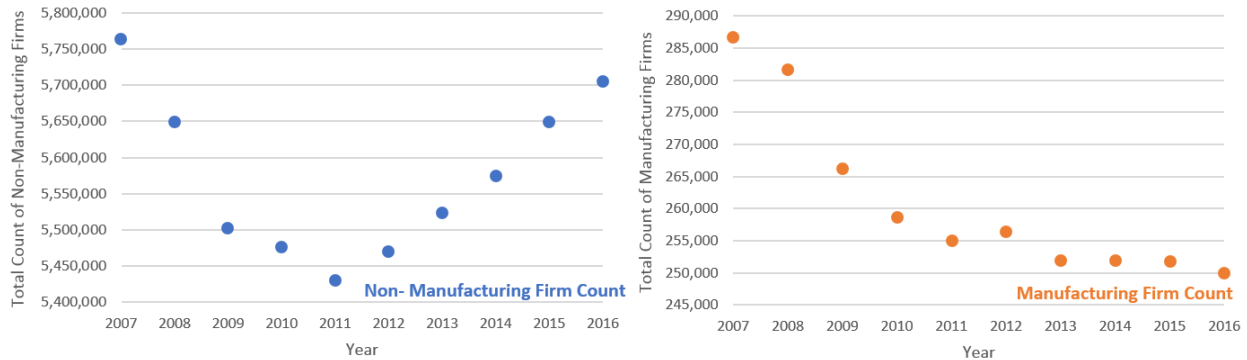


Figure F.1 Total Firm Counts 2007-2015: Non- Manufacturing Industries²¹ (left) and Manufacturing (right), data retrieved from Census Statistics of U.S. Businesses (SUSB)

Notice that non-manufacturing industries feature a trough in the total number of firms coincident with the timing of the Great Recession, however, while manufacturing industries firm counts feature a similar decline, they do not see a subsequent recovery/ sustained uptick in the total count of manufacturing firms between 2013 and 2016.

²¹ Non- Manufacturing Industries calculated by subtracting manufacturing firm counts (NAICS codes 31-33) from the total firm counts using the 2015 Census Statistics of U.S. Businesses (SUSB)

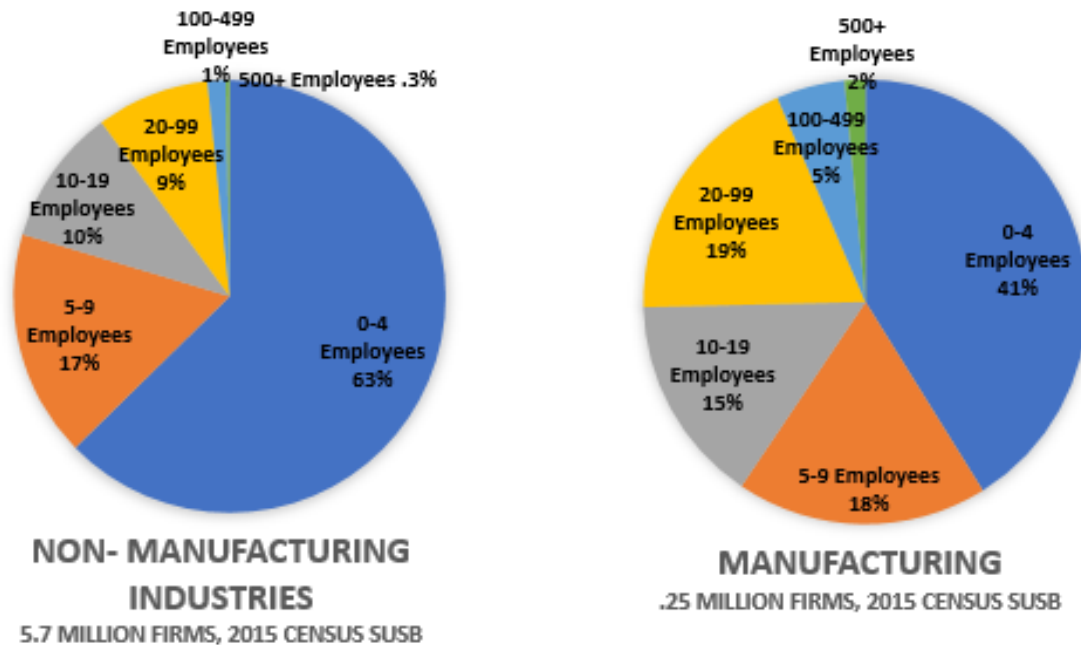


Figure F.2 Firm Size Distributions 2015: Non- Manufacturing Industries²² (left) and Manufacturing (right), data retrieved from Census Statistics of U.S. Businesses (SUBS)

There are several differences between the firm size distribution of U.S. firms in non-manufacturing versus those in manufacturing (see Figure F.2.). The firm size distribution across non-manufacturing firms is monotonic, that is the density of firms in each category declines as the firm size grows (from 63% to 17% to 10% to 9% to 1%). In contrast, manufacturing proceeds from 41% of firms with 0- 4 employees, to 18% with 5- 9 employees, to 15% with 10- 19 employees, then a larger proportion 19% with 20- 99 employees and 5% with 100- 499 employees. These results may be suggestive that given manufacturing’s capital intensity in many sectors, fewer firms find a 10-19 employee sized firm to be an efficient scale. In contrast, the 0-4 employees may reflect machining shops and similar undertakings.

Buera et al. (2011) argue that manufacturing, with larger scales of operation, is relatively more exposed to financial frictions than other sectors. The differences between small and large manufacturing firms across the business cycle is explored in Gertler and Gilchrist (1994), who find that in a high interest rate environment, small firms shed inventories and contract relatively more than large firms. Davis et al (1992) document the countercyclical nature of the job reallocation rate²³, which they argue is driven by larger, older, multi-establishment manufacturers. Comparatively, manufacturing has a lower proportion of firms with 0-4 employees and a higher proportion of each of the other categories. Overall, large firms (500 or more employees) comprise .3% of all non-manufacturing firms, however in manufacturing large firms comprise 1.5% of all manufacturing firms. That is, the manufacturing firm size distribution

²² Non- Manufacturing Industries calculated by subtracting manufacturing firm counts (NAICS codes 31-33) from the total firm counts using the 2015 Census Statistics of U.S. Businesses (SUBS)

²³ Davis et al. (1992), define the job reallocation rate to be the sum of the gross job destruction and gross job creation rates, their study employs data from 1972- 1986, and finds they are 11.3% and 9.2% respectively.

has proportionally 5 times as many large firms than the overall distribution, put another way, large (500+ employees) manufacturing firms comprised 20% of all large (500+ employees) firms in the U.S. in 2015. The relatively larger proportion of large manufacturing firms is consistent with Nuemark et al. (2011), which documents the importance of large firms in manufacturing to job creation. Dunne et al. (1989) provide one explanation for the presence of more large firms, arguing that manufacturing firms' plant failure rates fall with plant size and age, however there is a tradeoff between a manufacturer's rate of growth and probability of failure. Klepper and Simons (2000) also address the effects of firm size (among other factors) on the U.S. tire industry, arguing that larger and older firms influence technological evolution in the industry, increasing their survivability. Still, the disproportionate presence of large firms is quite interesting given the literature has documented a wage premium paid to workers of large U.S. manufacturing employers which can only be partially explained by observable characteristics of the workers and establishments (Troske 2006). It has also been documented that larger firms proportionally face higher relative prices of labor than their smaller competitors (Soderbom and Teal 2003 in the case of African manufacturing firms).

Appendix G: STEM Employees by Sector

Manufacturing represents 14.5% of employment for engineers, mathematical and computer science and scientific occupations, compared with 7.3% employment share for information and 4.3% share for R&D service companies.

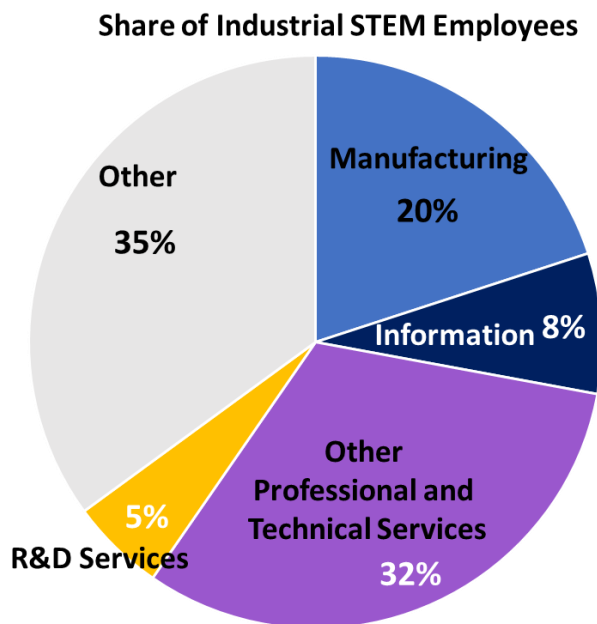


Figure G.1 Share of Industrial STEM Employees by Sector (Bureau of Labor Statistics 2019)

Appendix H: Example of Data Format

Table 3 H.1 BEA Input-Output Sub-Sector Data Format Example

| Commodities/Industries | | 111CA | 113FF | T019 | |
|------------------------|---|--------|---|------|-----------------------|
| IOCode | Name | Farms | Forestry, fishing, and related activities | ... | Total use of products |
| 111CA | Farms | 71893 | 901 | | 577472 |
| 113FF | Forestry, fishing, and related activities | 23901 | 9627 | | 101028 |
| 211 | Oil and gas extraction | ... | ... | | 570365 |
| 212 | Mining, except oil and gas | 2771 | 2 | | 128163 |
| 213 | Support activities for mining | ... | ... | | 157109 |
| 22 | Utilities | 4500 | 139 | | 656119 |
| 23 | Construction | 1782 | 44 | | 1701712 |
| 321 | Wood products | 409 | 53 | | 184489 |
| ... | | | | | |
| T005 | Total Intermediate | 259647 | 20529 | | 39432054 |
| V001 | Compensation of employees | 32707 | 26767 | ... | |
| V003 | Gross operating surplus | 98676 | 8273 | ... | |
| T00OTOP | Other taxes on production | 10256 | 1253 | ... | |
| VABAS | Value Added (basic prices) | 141640 | 36293 | ... | |
| T018 | Total industry output (basic prices) | 401286 | 56822 | ... | |
| T00TOP | Taxes on products and imports | ... | 599 | ... | |
| T00SUB | Less: Subsidies | -12068 | ... | ... | |
| VAPRO | Value Added (producer prices) | 129572 | 36892 | ... | |

Appendix I: Linear Regression of Inputs and Intensity Adjusted R&D by Sector

In addition to our production function estimation approach, we also attempt a very simple linear regression of output and value added over intensity adjusted R&D stock from key R&D spending subsectors. For example, we use the change in the ratio of value added by a subsector to the output of that subsector as a measure of the productivity of inputs to a sector, and then regress this value on intensity adjusted R&D stock from key subsectors.

We are unable to find evidence in these preliminary regressions to suggest that the returns to manufacturing R&D are captured by consumers of manufactured goods in a manner accounting for the underrepresentation of manufacturing in overall value added.

Table I.1 Regression Outputs for Change in Value Added Over Output (annual) (BEA,NSF 2019)

| Change in Subsector Value Added/Output ($R^2 = .274$) | | | |
|--|------------------|----------------|-------------|
| | Coefficients | Standard Error | P-value |
| Intercept | 1.70E-03 | 1.23E-03 | 0.17 |
| Change in Gross Value Added (U.S. Economy Wide) | 1.29E-16 | 6.90E-17 | 0.06 |
| Change in Inputs (Sector) | -6.71E-07 | 3.81E-08 | 0.00 |
| Machinery Intensity Adjusted 3 year R&D | 2.81E-11 | 1.02E-10 | 0.78 |
| Computer and Electronic Intensity 3 year Adjust R&D | 3.06E-12 | 2.69E-12 | 0.26 |

| | | | |
|---|------------------|----------|-------------|
| Motor vehicles, bodies and trailers, and parts Intensity 3 year Adjust R&D | -5.39E-12 | 5.66E-12 | 0.34 |
| Publishing industries, except internet (includes software) Intensity 3 year Adjust R&D | 1.18E-10 | 7.10E-11 | 0.10 |
| Computer systems design and related services Intensity 3 year Adjust R&D | -3.34E-10 | 6.40E-10 | 0.60 |
| Miscellaneous professional, scientific, and technical services Intensity 3 year Adjust R&D | 9.84E-12 | 8.46E-12 | 0.24 |

Appendix J: Regression Outputs for Estimation of Sub-Sector Output with Time Fixed Effects

In order to account for possible exogenous factors in each year of our timeseries (curtailed at either end by the limitations of our NSF time series R&D data and the construction of our intensity adjusted measure of R&D stock), we conduct and report in an estimation of the regression model in Table 1 extended to include time fixed effects for each year. We do not find that this revised model affects our evaluation that there is little initial evidence to support the R&D embodiment hypothesis for the dominance of manufacturing R&D spending.

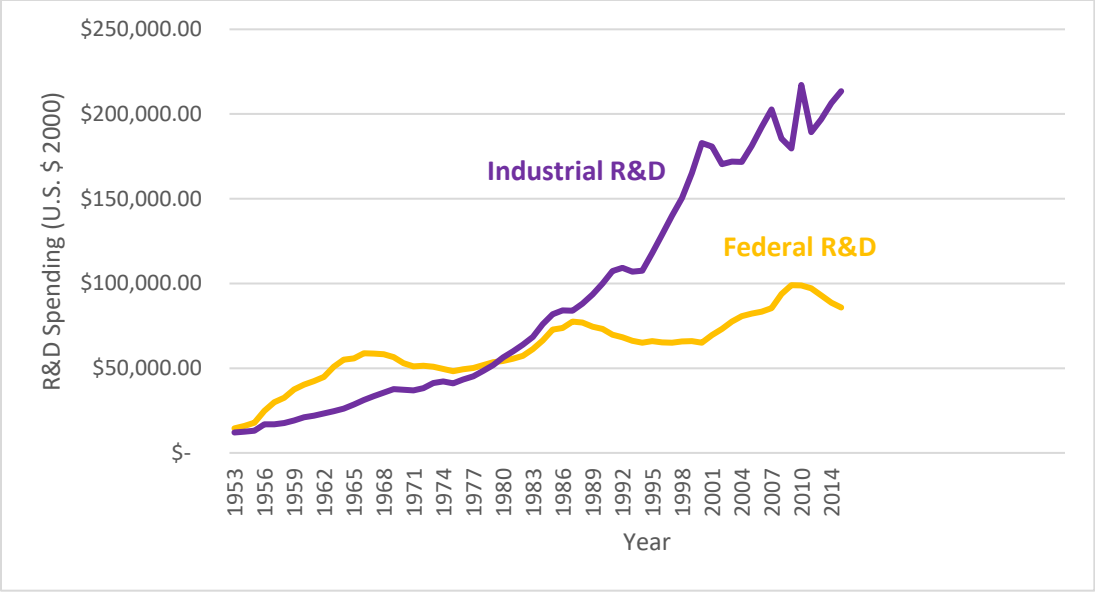
Table J.1 Regression Outputs for Estimation of Sub-Sector Output with Time Fixed Effects (BEA, NSF 2019)

| Dependent Variable: ln(Output) ($R^2 = .86$) | | | |
|---|---------------------|-----------------------|----------------|
| Independent Variables | Coefficients | Standard Error | P-value |
| Intercept | 0.394 | 0.186 | 0.034 |
| ln(Intensity Adjusted Top Manufacturing R&D Stock) | 0.022 | 0.007 | 0.002 |
| ln(Intensity Adjusted Service and Information R&D Stock) | 0.122 | 0.011 | 4.84E-24 |
| ln(Inputs from Other Sectors) | 0.952 | 0.013 | 1E-25 |
| Time Fixed Effects (year) | | | |
| 2002 | -0.066 | 0.065 | 0.305 |

| | | | |
|------|--------|-------|-------|
| 2003 | -0.086 | 0.065 | 0.185 |
| 2004 | -0.087 | 0.065 | 0.178 |
| 2005 | -0.104 | 0.065 | 0.108 |
| 2006 | -0.097 | 0.065 | 0.134 |
| 2007 | -0.117 | 0.065 | 0.072 |
| 2008 | -0.114 | 0.065 | 0.079 |
| 2009 | -0.051 | 0.065 | 0.435 |
| 2010 | -0.057 | 0.065 | 0.381 |
| 2011 | -0.046 | 0.064 | 0.471 |
| 2012 | -0.051 | 0.064 | 0.432 |
| 2013 | -0.036 | 0.064 | 0.578 |
| 2014 | -0.048 | 0.064 | 0.456 |

Appendix K. U.S. R&D Funding by Federal Government and Industry

Figure K.1. illustrates industrial R&D spending overtaking federal R&D spending, growing most acute after the 1980s.



K.1. Industrial and Federal R&D (1953-2015) (NSF, AAAS)