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Where Innovation Happens, and Where It Does Not

Benjamin F. Jones

13.1 Introduction

In the US, economic growth rates are remarkably steady. Per capita income has risen at approximately 2 percent per year in real terms since the late nineteenth century (Jones 2016). Innovation—the creation and implementation of new ideas—is typically seen as a primary explanation for this growth (e.g., Mokyr 1990; Romer 1990; Rosenberg 1982; Solow 1956). One measure of innovative effort is research and development (R&D) expenditure, which also appears in aggregate to be a broadly steady activity. For example, aggregate R&D spending in the US has fluctuated between the rather narrow bands of 2.1 percent and 2.8 percent of GDP for the past 60 years, with no apparent trend (National Science Foundation 2020).

This aggregate steadiness, however, masks remarkable underlying sectoral differences and dynamics, where specific industries have experienced extraordinarily different productivity gains and innovation investment. For example, agriculture and manufacturing have seen huge productivity increases, while other areas—such as housing, education, and the energy sector—have seen much less advance and, seemingly, much less innovative

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effort. Overall, we witness enormous, transformative advances in some sectors of the economy. In others, not so much.

These underlying differences raise fundamental questions. First, why would innovative effort differ so greatly across industries? Second, if the innovation engine operates weakly in some sectors, is this outcome inevitable? Third, what are the implications of these differences for meeting ongoing challenges? For example, as the US economy appears to be caught in an aggregate productivity slowdown, what roles and opportunities can individual sectors play in overcoming this challenge?

This chapter addresses these questions. The discussion integrates across the sector-specific analyses that constitute this book and provide rich and diverse perspectives. The goal here is a synthesis that, while necessarily incomplete and often speculative, provides a framework for thinking about the enormous diversity in innovative effort and productivity gains that we see.

Section 13.2 of this chapter outlines the enormous sectoral differences in innovation, with an emphasis on the sectors examined in this volume. Sections 13.3–13.5 then consider potential explanations for this variation. The analysis is organized around a simple framework for considering the incentives to innovate. Namely, an agent considering an investment in innovation is making some assessment of its value, and effort at innovation should naturally increase when the expected return on an innovation investment is higher. The question then is: Why is the expected return to innovation higher in some industries and lower in others?

The synthesis offered here emphasizes three features that determine the return on innovation investment and that vary across industries. First is demand. Demand incorporates market scale, willingness to pay for a given innovation, and buyer uncertainty. Demand features are the subject of section 13.3. Second is supply. "Supply" here means the fixed costs of creating a productivity-enhancing advance, as well as the ongoing costs of producing, marketing, and distributing this advance. Supply features are the subject of section 13.4. Third is institutions. Institutions here include the standard tools of innovation policy (e.g., patents and public R&D funding) as well as sector-specific regulatory environments and market structure. Institutions are the subject of section 13.5. To the extent possible, this chapter will use this demand-supply-institutions framework to understand the varying efforts at innovation across sectors and the various outcomes that result.

Overall, the picture that develops is multifaceted. The potential explanations for sectoral variation are not easily reduced to a small set, with different sectors often suggesting somewhat different opportunities and challenges. At the same time, an important and relatively contained set of features appear relatively elastic to policy. While fundamental demand and supply features can be rooted deeply in preferences and technological possibilities, institutional features are often, in principle, more malleable. Section 13.5

thus further considers opportunities—through institutions and policy—to accelerate innovation in lagging sectors, such as education, health services, and energy, with applications to diverse challenges, including the productivity slowdown and climate change.

13.2 Industry Variation in Innovation

Innovation differences across industries can be measured through both inputs and outputs. On the input side, a standard approach measures R&D expenditure. One might also look at new venture investment. On the output side, one might look at intellectual property outcomes (i.e., new patents, copyrights, and trademarks), the introduction of new goods and services, productivity growth, market value, or, in a more equilibrium context, market shares. All these approaches have limitations, and one consequently has to keep caveats in mind when studying these data.[1] That said, substantial evidence links these measures in natural ways, and they can paint fairly coherent pictures.[2]

Table 13.1 presents R&D expenditure for various sectors discussed in this volume. The root data source is the National Science Foundation's Business Research and Development and Innovation Survey (BRDIS). BRDIS is a firm-level survey that includes information on R&D and sales, with results reported by industry NAICS code. BRDIS is linked to US Census establishment data and aims to produce a relatively comprehensive picture of R&D for the US and its businesses.

An advantage of BRDIS is that it includes the firms' worldwide sales, which may be more useful than domestic sales or output for thinking about firms' R&D decisions. However, an important caveat with the BRDIS data is that it only includes the sales of firms that report positive R&D expenditures. That is, the survey omits firms that report no R&D. This can make R&D per unit of output look high in a sector, when in fact it is cloistered in a few firms and overall R&D as a share of industry output is very low. R&D-to-sales ratios in the BRDIS data can then lead to odd results, especially for service industries, where most firms report no R&D.[3] For service sectors, table 13.1

1. For example, innovative effort may not be credited explicitly as R&D (e.g., Brouwer and Kleinknecht 1997), patents may apply to a relatively narrow class of product innovations, and total factor productivity measures require production function and input measurement assumptions that are susceptible to error (e.g., Collard-Wexler and De Loecker 2016; B. Jones 2014).

2. For example, firm-level R&D expenditure and patent production are closely linked to the firm's market value and broader productivity gains (e.g., Hall, Jaffe, and Trajtenberg 2005; Hall, Mairesse, and Mohen 2010; Kogan et al. 2017).

3. For example, looking at "real estate and rental leasing" (NAICS code 53), one finds that R&D expenditures amount to 8.84 percent of worldwide sales in BRDIS. This result may seem surprising, as this sector does not obviously appear very engaged in R&D. Digging deeper, one finds that the worldwide sales of these firms is only $5 billion in BRDIS, whereas the US Census's Service Annual Survey (SAS) indicates total sales of $633 billion for employer-firms

Table 13.1 Variation in R&D intensity: Examples

Chapter	Industry	NAICS	R&D ($ billions)	Sales ($ billions)	R&D/sales (percent)
Manufacturing (1)	Manufacturing	31–33	306.6	7,484	4.08
Information Technology (2, 7)	Information	51	86.0	1,498[c]	5.74
	Computer and electronic products	334	90.9	1,267	7.18
Energy (3)	Mining, extraction, and support activities	21	3.5	487	0.72
	Utilities	22	0.3	570[c]	0.06
	Engines, turbines, and power transmission equipment	3336	2.3	52	4.40
Agriculture (4)	Agriculture[a]	—	5.6	214	2.63
Education (8)	Education[b]	—	—	—	0.20
Housing (10)	Real estate and rental and leasing	53	0.5	633[c]	0.08
Health care (11)	Health services	621–623	1.0	2,254[c]	0.04
	Pharmaceuticals and medicines	3254	99.3	767	12.94
Transportation (12)	Transportation and warehousing	48–49	0.5	876[c]	0.06
	Automobiles, bodies, trailers, and parts	3361–63	28.2	1,134	2.49
	Aircraft, aircraft engines, and aircraft parts	336411–13	14.1	394	3.58

Notes: R&D expenditure is primarily taken from the Business R&D and Innovation Survey (BRDIS). This R&D is worldwide R&D performed or funded by US private sector companies with at least 5 employees. Worldwide sales are primarily taken from BRDIS. The data year is 2016. Exceptions as noted are (a) agriculture, where data is taken from Alston and Pardey (this volume); (b) education, where the data are from the President's Council of Advisors on Science and Technology (2010); and (c) service industries, where R&D expenditure is still taken from BRDIS but sales are taken from the US Census's Service Annual Survey (2016).

thus replaces sales from BRDIS with the relevant industry-wide sales from the US Census's Service Annual Survey.

The picture of R&D that emerges in table 13.1 is one of enormous variance. Manufacturing sectors typically show large R&D expenditure rates. This is true for manufacturing overall, where the R&D-to-sales ratio is over 4 percent and appears in several subcategories of manufacturing relevant to the chapters in this book, including "computers and electronic products"; "pharmaceuticals and medicines"; "engines, turbines, and power transmission equipment; "automobiles, bodies, trailers, and parts"; and "aircraft, aircraft engines, and aircraft parts." Service industries, by contrast, show much less R&D. The exception is information services, which show an R&D rate (7.18 percent) exceeding that in almost all the manufacturing sectors. The broader story for services is one of very little R&D, with R&D-to-sales ratios often less than 0.1 percent.

It is further notable that the manufacturing versus services distinction tends to operate within related clusters of activity. For example, consider health. We see virtually no recorded R&D in health services, which incorporates ambulatory health care services (NAICS code 621), hospitals (NAICS code 622), and nursing and residential care facilities (NAICS code 623), where the R&D-to-sales ratio overall is 0.04 percent. Yet there is enormous R&D in pharmaceutical and medicines, where R&D rates per dollar of sales are 320 times larger. Similar stories appear for transportation, where transportation and warehousing services exhibit very low reported R&D, whereas relevant transportation manufacturing, including both automobiles and aircraft manufacturing, show R&D-to-sales ratios that are 42 and 60 times greater, respectively. Industries related to the energy sector are once again similar. Utilities show virtually no R&D per unit of sales (0.06 percent), mining and extraction show R&D rates 12 times higher, and relevant energy production machinery shows R&D rates 6 times higher than that.

The remaining sectors displayed in table 13.1 are agriculture, education, and housing. Agriculture presents relatively substantial private R&D-to-sales ratios and is more in line with manufacturing. The agriculture numbers include agricultural machinery as well as chemical and biological R&D investment and are taken from Alston and Pardey (chapter 3, this volume).[4]

in this NAICS code. Normalizing the measured R&D expenditure by total sales for this sector reduces R&D expenditure to 0.08 percent of output. The housing analysis by Kung (chapter 11, this volume) makes a similar correction. Another sector where this correction makes a large difference is "health services" (NAICS codes 621–623), where BRDIS shows worldwide sales of R&D-performing firms of $81 billion, while SAS shows that total revenues for all employer firms in this industry are $2.254 trillion. In some service sectors, such as "information" (NAICS code 51), firms typically perform R&D, and the difference in sales between BRDIS ($1.329 trillion) and the SAS ($1.498 trillion) is modest.

4. These numbers do not include public R&D, which is substantial in agriculture and suggests more intensive R&D investment; see Alston and Pardey (chapter 3, this volume) for broader measures.

By contrast, housing services show very little R&D, in line with typical service sectors. Finally, education, while hard to measure, also appears to have very low rates of R&D, even including public R&D (Chatterji and Jones 2012).

Due to data limitations, table 13.1 does not include three areas analyzed in this volume: retail services, creative arts, and the US federal government. But drawing on the relevant book chapters, additional comments on innovation variation are possible. First, Lafontaine and Sivadasan (chapter 6, this volume) show that the retail sales remain dominated by traditional brick and mortar outlets, with e-commerce in 2017 capturing only 7 percent of retail sales and big-box retail (warehouse clubs and supercenters) capturing only 8 percent. Retail services may thus look like other services, with a small number of R&D-intense firms (e.g., in e-commerce) amid a much broader industrial footprint featuring relatively little R&D effort (traditional brick and mortar retail). Second, while the creation of books, music, and movies are not included in BRDIS, Waldfogel (chapter 8, this volume) shows that these industries exhibit increasing innovative effort, measured as a rapidly increasing labor force of creative workers, and expanding production of new material. These creative arts appear to reflect the broader information technology (IT)-enabled booms in many sectors, where production and distribution costs have dramatically fallen amid IT advances and have encouraged entry, as discussed further below. Third, Bruce and Figueiredo (chapter 9, this volume) demonstrate the large scale of intramural research activity in the US government. While government entities are not covered in BRDIS, it is clear that substantial R&D is proceeding in many executive branch agencies, which all told employ over 60,000 R&D-focused scientists. Intramural R&D expenditure (which totals over $30 billion per year or over 2.3 percent of total federal discretionary spending) suggests that US government agencies, including the Department of Defense, Health and Human Services, US Department of Agriculture, and NASA, invest relatively heavily in pushing the frontiers of science and technology.

In terms of overall outcomes, looking to the economy as a whole, one can consider patterns of structural change. Figure 13.1a presents a standard picture, showing how the GDP shares of agriculture and manufacturing have declined dramatically while that for services has risen. A natural interpretation follows Baumol's cost disease (Baumol 1993), where a declining sectoral share is consistent with rapid relative progress of productivity in that sector. For example, relatively rapid advances in manufacturing productivity are associated with declining manufacturing GDP shares not only in the US but also in more global contexts (e.g., Bergoing et al. 2004; Pilat et al. 2006). Conceptually, if demand curves are sufficiently downward sloping, then rapidly advancing productivity in a sector causes its prices to fall sharply as supply shifts outward, and the sector's GDP share declines even as quantity rises. The converse implication is that the lagging sectors will see their GDP shares increase. One could then interpret figure 13.1a as indicating relatively

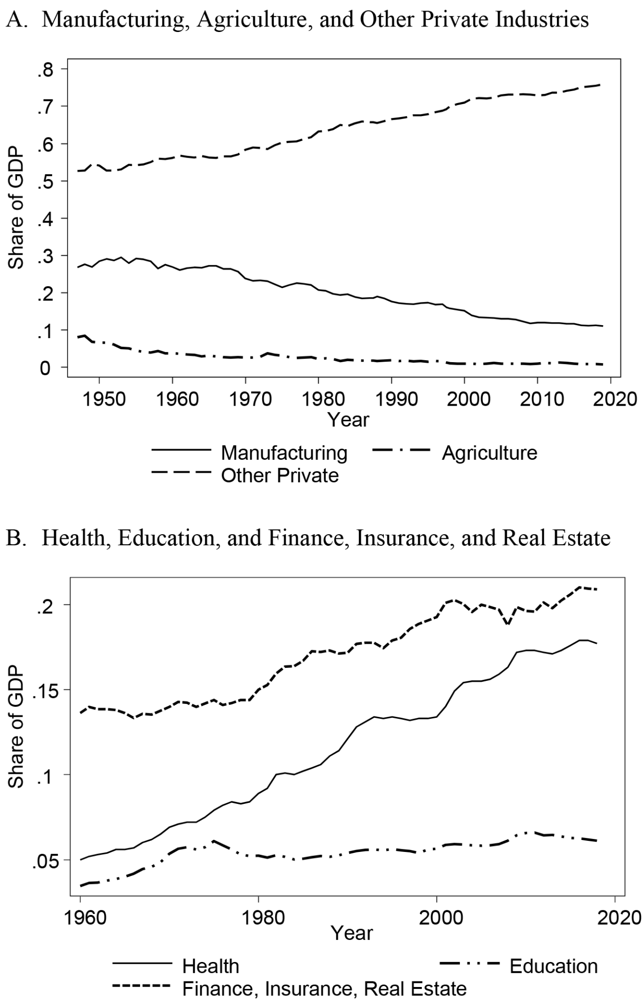

Fig. 13.1 The evolution of sectoral GDP shares

rapid productivity advances in agriculture and manufacturing, leaving the economy stuck with a greater share of activity and resources devoted to the sectors we are not very good at—here, services.

Figure 13.1b extends the services picture. We examine three large sectors that are primarily based on services: health; education; and finance, insurance, and real estate. These sectors represent substantial and increasing shares of the overall economy. These sectors are also areas that appear to see little overall R&D, as shown in table 13.1.[5]

5. Note that the Bureau of Economic Analysis's industry-level value-added output series does not match perfectly with the specific NAICS-level organization of R&D expenditures

Overall, we see huge variation in R&D expenditures across sectors. While innovation effort is imperfectly measured by R&D expenditure, outcomes seem to follow related equilibrium output patterns. Service sectors, such as health services and education, see very little measured R&D effort and rising output shares. Manufacturing and agriculture see much larger measured R&D effort and declining output shares.

One can of course track inventive outcomes and productivity gains at more micro levels, but for the purposes of this chapter, the perspective of aggregate output share is useful. In particular, the important equilibrium idea here is that a rising GDP share can be symptomatic of low rates of progress. Moreover, since the overall economy is increasingly made up of the lagging sectors, it suggests that overall progress might slow down if progress in these lagging sectors remains slow. This issue substantially raises the stakes in understanding, and potentially overcoming, the forces that limit innovation in these sectors. The rest of this chapter considers reasons that innovation may proceed faster in some sectors and more slowly in others.

13.3 Demand

The proverb "necessity is the mother of invention" suggests a central role of demand in driving technological advance. That human wants and needs may guide innovative effort is natural, and there is good evidence in the literature that innovation responds to demand. For example, natural experiments regarding pharmaceuticals and vaccines show that expanding demand does indeed drive more innovative activity (e.g., Acemoglu and Linn 2004; Finkelstein 2004). This section uses this lens to consider variation across sectors, drawing on sectoral examples from the book. As we will see, demand-side considerations seem important yet insufficient for understanding the different innovation experiences of different industries.

13.3.1 Scale and Price

From a microeconomic perspective, straightforward logics connect innovative investment to demand. If it is possible for the innovator to appropriate the value of the innovation (e.g., through advantageous market structure or a patent), then the value of such an innovation should be increasing in both the willingness to pay per customer and customer scale, so that more demand will attract more innovative effort. Further, if there is a fixed cost to the creation of the idea, then the innovative process naturally faces increasing returns to scale, again suggesting a key role of demand. These demand-side logics are often explicit in venture capital funding, where the "total addressable market" is a prominent consideration for investment.

in BRDIS, so figure 13.1 uses related but somewhat distinct industrial categorizations as in table 13.1.

At a macro level, one may also expect the scale of demand to play a central role. For example, consider endogenous growth models where innovation is getting harder with time (e.g., B. Jones 2009; C. Jones 1995; Kortum 1997), meaning that more people are required to produce a given percentage productivity advance. In this context, rising demand is essential to maintain innovation investment, because while innovation costs are increasing, the value of a given success also increases as the overall market expands. This demand-side expansion maintains incentives to invest in R&D and sustains steady-state growth.

Multiple chapters in this volume speak to these logics. For example, Fuchs et al. (chapter 1, this volume) explore US manufacturing and suggest the importance of scale. A main finding is that US manufacturing firms produce a substantial share of value added outside the US, so that globalization appears to extend the market size for an innovation. With R&D returns substantially realized abroad, this scale logic provides some explanation for high (and sustained) R&D expenditure by US manufacturing firms. Popp et al. (chapter 4, this volume) study the energy sector and suggest the key role of price. Namely, R&D investment in clean energy technologies rises when energy prices are high and falls when they are low. As substitutes for other energy production technologies, a high willingness to pay can then explain clean energy investment, both historically and today.

Further examples come from pharmaceutical R&D. Challenges in drug development for niche diseases, for which there are few consumers, suggest the importance of scale and the need for policy interventions (Drummond et al. 2007). Separately, biomedical firms invest relatively little in diseases like malaria that largely affect lower-income consumers, who have less capacity to pay (Kremer and Glennerster 2004). These demand-side problems further point to the importance of demand-side policy interventions, such as advanced purchase commitments, to pull forth innovations (Kremer 2000).

These examples suggest that one might understand innovative effort in substantial part by considering how scale and willingness to pay affect the market value of an innovation. However, it is also clear when looking at table 13.1 that there are sectors with seemingly enormous demand that see extremely little innovation. For example, all individuals in the US economy experience education and health services, and often spend substantial sums for these services, yet there are appears to be very little innovative effort in these sectors. This suggests that simple price and quantity signals paint a limited picture.

13.3.2 Uncertainty and Salience

A perhaps less obvious but potentially central issue on the demand side concerns consumer uncertainty about the utility of an innovation. That is, consumers may have difficulty assessing whether an innovation is actually worth buying, and this uncertainty may be a fairly fundamental feature of the product or service. If consumers are unable to easily evaluate the good, then reaching the market, even if it is large, may be challenging, lowering the return to innovative effort.

Education services provide a potentially useful example along these lines. While the scales of primary, secondary, and tertiary education are all huge, and costs per student are large, it is often difficult to say what is “better” in this space. The measurement issue is partly one of duration, where important life outcomes from a given educational approach are determined over a long horizon. Proving that any newly innovated approach is better is very difficult in a short period of time. The measurement issue is also one of complex goals and unsettled trade-offs, where the objectives of education are multidimensional and subject to debate. For example, an innovation that improves mathematics scores may be helpful on some dimensions, but what happens if it crowds out historical knowledge, or creativity? If families, as well as teachers and school officials, are unclear about how to assess the benefits from an innovation, selling innovations becomes hard. And if selling such innovations is hard, it may not be surprising that little such innovation investment occurs (Chatterji and Jones 2012). Furthermore, in making choices amid opaque evidence, school systems may end up investing in new technology that may not improve learning. Investment in the “shiny new object” (e.g., computer tablets) may then present a community with a veneer of innovation, while schools fail to create or adopt provably effective pedagogical advances.

Health services appear to face some similar difficulties. It is often difficult to know that a given approach is better in terms of patient outcomes. Patients may recover despite bad care or, conversely, have adverse outcomes despite high-quality care. This noise muddles assessment. Patient selection issues also undermine measurability; for example, attempts at doctor and hospital scorecards are bedeviled by selection issues in the populations served (Dranove et al. 2003). Furthermore, there are difficult balancing issues (somewhat akin to education) across complex endpoints, where success against the diagnosed disease must be weighed against side effects and other quality of life issues.

One sector where we do see enormous innovative effort in health is in pharmaceuticals and medicines. In this case, an explicit (and onerous) process of approval exists through the US Food and Drug Administration (FDA) and similar agencies elsewhere in the world. Side effects are explicitly assessed, and randomized controlled trials are used to prove that an innovative medicine advances the standard of care. Thus, we see that high levels of certainty can be created even where it is hard, and that R&D effort can be enormous when this provability element is created. The FDA example further suggests the importance of institutions in promoting innovation in light of buyer uncertainty, which we return to below.

Coming back to manufactured goods, the qualities of these goods, in contrast to education and health services, may be highly salient. For example, an internal combustion engine, microprocessor, or chemical process that produces the same output but at lower cost will presumably be adopted, as the buyer's self-interest and market forces push in this direction. While quality may not fully be obvious with some manufacturing goods (e.g., the durability of new capital equipment), the uncertainties do seem much more limited compared to things like educational services or hospital services.

Altogether, demand-side considerations—scale, price, and uncertainty—appear to be useful and even powerful ways to think about sectoral variation in innovation. Yet, looking at table 13.1, it is not obvious that these features are anywhere near enough to understand the variation in innovation across sectors. Namely, many sectors account for large amounts of GDP and see extremely little innovation, including sectors like transportation and warehousing services, and real estate, where scale is large, and an uncertainty story does not seem germane. This observation suggests that technological and institutional features may critically important, as we turn to next.

13.4 Supply

The cost side of innovation and associated technological opportunity provide an additional lens for viewing innovation effort (e.g., Jaffe 1986; Scherer 1965). Similar technologies may suggest similar cost-side features, which in turn may push toward broadly similar innovation returns and investment. This cost-side similarity can, in turn, map into sectoral innovation tendencies, if industry classification schemes group sectors in ways that suggest technological affinities. For example, manufacturing processes may in general involve relatively common physical and engineering principles and hence similar technological opportunities, even though the products themselves (e.g., processed foods, printed books, building materials, and aircraft engines) have relatively unrelated sources of demand. Then the observation that manufacturing sectors typically see very high R&D rates and productivity gains may be a statement about common (low) innovation costs as opposed to common (high) demand. In this section, we examine various cost and technology features.

13.4.1 Cost Features

To further articulate costs, we can write the expected present value V of an innovation as

$$V = \Pi(c,s) - F$$

where F is the fixed cost of creating a new product or process, and $\Pi(c,s)$ is the net present value of profits from this innovation once it is created. Other things being equal, the expected value (V) is declining in the fixed cost (F), the per-unit production costs (c) of the new product or service, and the per-unit sales cost (*s*), which includes sales, marketing, and distribution costs for the new product or service. By this logic, innovation will be relatively high when the cost parameters *F*, *c*, and *s* are relatively low.

An example suggesting the relevance of this cost perspective is the creative arts, where we have witnessed an explosion of movies, television programs, online videos, music production, and new books. As Joel Waldfogel argues (chapter 8, this volume; Waldfogel 2018), this explosion in innovation follows from technological changes in the cost of creating (*F*), duplicating (*c*), and distributing (*s*) new works. For example, musicians today can record at home using sophisticated and inexpensive software. The music can then be duplicated digitally at essentially zero marginal cost and published instantaneously at close to zero cost to followers online. As such costs have declined, it is not surprising that we have witnessed a huge expansion of these creative outputs. Similar cost features appear among other digital products, including in mobile application development, where the Android ecosystem adds over 30,000 new apps in a typical month,[6] further suggesting that innovation effort will be large when the relevant innovation costs are low.

By contrast, consider the energy production sector (Popp et al., chapter 4, this volume). Here innovation costs tend to be high. At one extreme, nuclear fusion has seemingly vast demand-side potential but innovation requires enormous fixed costs for experimentation. In practice, we see relatively few independent innovative efforts in fusion technologies, and these efforts are supported by the public sector. Compared to nuclear power innovations, clean energy technologies like wind and solar power generation see relatively lower innovation costs and have meanwhile seen more rapid technological and market progress.

Uncertainty is also germane (e.g., Arrow 1962; Kerr, Nanda, and Rhodes-Kropf 2014). Beyond the demand-side considerations of consumer uncertainty discussed above, a basic form of uncertainty is that the technological approach will fail, either because the technology doesn't work or, more generally, is not cost effective. Investment portfolio strategies may overcome individual project risk, but this will be difficult for resource-constrained agents when the fixed cost of each innovation bet is high. This feature may suggest why venture capital investment and startup activity in energy technologies has traditionally been relatively low (e.g., Ghosh and Nanda 2010). By contrast, sectors that feature low innovation costs (whether music or mobile apps) may see substantially more innovation attempts and more resulting innovation. Interestingly, Popp et al. (chapter 4, this volume) show that while clean energy patenting and startup activity has been plummeting since 2010, activity is steady or increasing for smaller and more modular energy technologies, which may have cost advantages along these lines.

6. For Android metrics, see https://www.appbrain.com/stats/number-of-android-apps.

13.4.2 Scale and Scalability

Sectors vary in the fixed costs of creating a useful invention. But the costs of producing and distributing the new product or service—the "scalability" of the innovation—may be at least as important. Other things being equal, when the scalability of the product is high, the investment becomes more attractive. These scalability costs often seem essential for understanding innovative effort.[7]

Digitization, and the massive innovation investments therein, seems to hinge significantly on this low-cost scalability. While the fixed costs of developing a new digital product may be high or low—compare enterprise software with a simple mobile application—a common feature of digital products is that they can be duplicated and distributed at very low cost. Returning to services, "information services" see R&D rates that exceed the average in manufacturing (see table 13.1). Information services are a striking outlier among service sectors, and with its expanding set of uses, computing and information approaches are often recognized as a "general purpose technology." At root, closely related technological methods—with common types of (low) scalability costs—are being applied to an ever-expanding range of demands. This phenomenon appears throughout this volume.

Consider, for example, the entrance of digital innovations into housing and transportation services, where measured innovation rates have historically been extremely low (see table 13.1). Kung (chapter 11, this volume) examines the housing sector, including new technology businesses that facilitate real estate transactions (e.g., Redfin, Trulia, and Zillow) and homestays (e.g., Airbnb and HomeAway). These scalable digital platforms connect buyers and sellers, providing key information—locations, reviews, histories, and photographs—to reduce search costs and limit uncertainty. These businesses, which have received substantial venture capital backing, have achieved scalability in dimensions of the real estate and housing sectors that heretofore have been fractured. Interestingly, while real estate R&D is measured to be only 0.08 percent of sales (table 13.1), looking narrowly at the firms in this sector that actually perform R&D in the BRDIS survey, the R&D share of sales rises to 8.84 percent. This looks like a lot like information services in general. It suggests how, when new technology allows for scalability, R&D investment and disruptive business models can enter formerly less-innovative sectors.

Turning to transportation services, we see a similar phenomenon. Choe, Oettl, and Seamans (chapter 5, this volume) discuss the rise of ridesharing as well as efforts to develop autonomous vehicles in the broader context of the transportation sector. Like housing services, transportation and warehous-

7. Business and new venture language is often oriented along these forces, where attractive "unit economics" equates to low costs of producing additional instances of the good or service and attractive "customer acquisition costs" equates to low costs of reaching buyers.

ing services see very low R&D shares of sales (0.06 percent in table 13.1). Yet again like housing services, transportation has recently seen the advent of disruptive, venture-backed business models (e.g., Uber and Lyft) building on digital platforms. While autonomous vehicles are a prominent area of innovative effort, venture capital is also targeting logistics and warehousing, with many bets on IT-enabled approaches.

Finally, Delgado, Kim, and Mills (chapter 7, this volume) explore the "servicification" of the US economy, investigating elements of the transition from manufacturing to services. Abetted by digitization, innovation and the STEM workforce are increasingly located in business-to-business services. This process can be seen in established firms, for example, in the rise of cloud computing services for companies like IBM. More generally, Delgado, Kim, and Mills study 2,000 large incumbent manufacturing firms and see a marked increase in the employment of these firms toward business-to-business service activities.

13.4.3 Nature's Opportunities and Constraints

In tackling the cost side of innovation and its capacity to explain difference across sectors, a fundamental aspect may be the varying technological opportunities that nature provides. For example, digitization and its expanding role are greatly facilitated by Moore's Law, yet gains in engine efficiency are held back by the Carnot maximum.[8] Viewed in terms of the fixed cost of invention, R&D investments in microprocessors can repeatedly produce large percentage gains in performance, while R&D investments in a new engine design, no matter how large, cannot achieve such substantial gains.

To the extent that technological opportunities vary, observers may be tempted to focus on fields and industries where progress has been profound. Looking back through time, sectors where productivity has advanced rapidly have driven economic growth, sectoral dynamics, and social change. Yet this backward-looking perspective is incomplete. For example, rapid computing advances must increasingly be viewed in the context of an apparent productivity slowdown at the aggregate level. Looking forward (and returning to Baumol's cost disease), the harder things take on increasing importance. That is, GDP and future progress depend less and less on the sectors we have found relatively easy to advance (like agriculture, manufacturing, or now digital technologies), and increasingly on the sectors that continue to be hard, which make up a growing share of the economy. Nature's constraints may then ultimately be more important than nature's bounty, and the difficult problems—in energy, transportation, construction, health services, education, and government services—only come to matter more.

8. While Moore's Law is partly endogenous to demand and institutions, it also relies on fundamental technological opportunities among computing technologies.

13.5 Institutions

If innovation rates come down to fundamental and largely immutable demand and supply features, then altering the progress of different sectors would be largely out of our hands. However, a substantial part of demand and supply side features may depend not only on basic human preferences and natural laws but also on institutions and policies. This section draws out several institutional roles, with two objectives. First, institutions can help further explain sectoral variation in innovation. Second, institutions can provide explicit mechanisms to advance sectors in which needs may be great but innovation lags.

The institutional parts of the innovation system are manifold: They include intellectual property, R&D tax credits, basic research institutions (e.g., the National Institutes of Health [NIH]), and antitrust policy, among others. While surveying this entire landscape is beyond the scope of this chapter, several institutional features may help explain sectoral variation and are be emphasized here. These include the role of institutions in influencing innovation incentives, advancing basic research, and achieving scalability.

13.5.1 Institutions and Appropriability

A basic issue in innovation incentives is appropriability, which governs the capacity of the innovator to capture a significant share of the innovation's value. In general, appropriability will be low if others can successfully enter and compete using the new idea. The imitator(s) will have a cost advantage over the initial innovator by not having paid the fixed cost of creating the new product or service. With competitive entry reducing post-innovation profits, the initial innovator will see lower returns on the investment and may even face a net loss. Thus, even if the social value of innovations is high, we may expect little innovation if appropriability is low.

Appropriability naturally depends on institutional and market structure features. Consider first intellectual property institutions. Returning to sectoral variation (see table 13.1), one might imagine that patentability could be an important part of the story. New manufacturing products, as tangible goods, seem especially amenable to receiving patent protection, while service industries and various kinds of business model and service innovations seem less so. And trade secrets may provide effective protection for goods with complex manufacturing processes yet do little for service innovations. Low R&D in service industries could then in part be a symptom of weak appropriability in the intellectual property dimension.

Patenting is a complex institution with many trade-offs—for example, between upstream and downstream innovation (e.g., Sampat and Williams 2019; Scotchmer 1991), and its importance for appropriability appears to be mixed and sector dependent (e.g., Levin et al. 1987). But patenting seems to be essential for understanding innovation in some sectors. For example, pharmaceutical innovation typically features very high fixed R&D costs, and recouping these costs would be difficult without patent protection (Mansfield 1986). Separately from patents, trade secrets are important means of appropriability in many manufacturing industries (Cohen, Nelson, and Walsh 2000). Overall, to the extent that patents and trade secrets fit better with manufacturing industries, it is an interesting and open question whether service sector innovation lags in part due to reduced access to these intellectual property institutions.[9]

Separate from intellectual property, market structure can influence appropriability. The relationship between market power and innovation is a deep research topic with diverse theoretical and empirical results (e.g., Arrow 1962; Cohen 2010; Gilbert and Newbery 1982; Schumpeter 1942). The net implications of market structure can be difficult to elucidate generally and appear to be nonlinear (e.g., Aghion et al. 2005). Moreover, many theoretical results frame market power in terms of single-product firms, which may not fit well with actual business structures in many industries. All this suggests that, when seeking to explain cross-industry variation in innovation, market power reasoning may not provide an obvious or simple perspective. At the same time, different sectors have distinct technological and institutional features related to market power that seem relevant to the variation we see.

As one force, market power over a complementary asset may allow a firm to capture value from innovative effort (Teece 1986). One might then expect more innovation from incumbents in sectors where businesses can create market power through complementary assets. For example, for pharmaceutical firms, advantages in regulatory compliance (through FDA trials) and dominant sales networks (to health providers) can be seen as complementary assets that assist value capture, which may further help explain high R&D investment by incumbents—and why entrants tend to sell themselves to the incumbents (e.g., Gans and Stern 2003). In IT, network externalities can lead to dominant firms with substantial market shares and market power. A tendency toward winner-take-all competition for digital platforms may help explain the high level of venture capital devoted to IT businesses (i.e., because winning most of the market is actually possible, and the value of success becomes so high) and also encourage ongoing R&D among the winners (i.e., controlling the winning platform allows ongoing value capture). However, an incumbent's dominance of a necessary complementary input may dissuade entry by others, potentially resulting in less innovation and dynamism in the sector.[10] The sector-wide effect is ultimately unclear. What

9. See also Moser (2005) for historical evidence that the availability of distinct intellectual property forms affects the direction of innovation.

10. The bargaining power advantage of the incumbent firm (with the complementary asset) may dissuade entry. However, in a repeated game, reputational considerations may drive the incumbent firm to avoid taking advantage of any specific entrant, because the incumbent firm benefits by acquiring innovations that are complementary to its business and thus wants to encourage entry. So it is not obvious that innovative entry is discouraged. The broad scale of entry by biotechnology firms and IT firms, and the large scale of acquisitions in these sectors,

is clearer is that certain highly innovative sectors, like pharmaceuticals and IT, feature incumbent firms with dominant complementary assets. Whether variation in innovation efforts across industries can be explained along these lines is an interesting and open research question.

High fixed costs of entry, which support oligopolistic market structure, may also be germane for understanding the locus of innovation effort, including in vertical supply chains. For example, airframes (e.g., Boeing and Airbus) and jet engines (e.g., General Electric, Pratt & Whitney, and Rolls Royce) are industries with large barriers to entry, very few players, and the resulting profitability to support high R&D investment. By contrast, downstream air transportation companies (airlines, air cargo) are more competitive and appear to have less resources to invest in R&D. In automobile transportation (see Choe, Oettl, and Seamans, chapter 5, this volume), note that the advent of ridesharing follows from R&D-intensive upstream oligopolistic players (e.g., Uber and Lyft). Similarly, while farms are extremely competitive, upstream providers of farming inputs (e.g., machinery, seeds) have a more oligopolistic market structure and see high ratios of R&D to sales (Alston and Pardey, chapter 3, this volume). Arguably, the more oligopolistic parts of the supply chain may have favorable R&D conditions, reflecting the inverted-U of innovation effort in market structure that appears in some conceptual models and broader empirical evidence (e.g., Aghion et al. 2005).

As another example linking institutions and appropriability, natural monopolies may face innovation challenges through intermediating regulations. Utilities are natural monopolies that appear to see little R&D (Popp et al., chapter 4, this volume, and table 13.1). Having high fixed costs, electricity distribution, water, and sewage systems (and more classically telecom, cable television, and mail services) do not easily support multiple providers in a single market. Public ownership or price regulation are common institutional responses. However, such institutional intervention can undermine innovation incentives. For example, innovations that lower costs may simply result in lower regulated prices, providing little incentive for the regulated firm to undertake improvements (e.g., Vickers and Yarrow 1995).

Overall, appropriability issues speak to the basic incentives to innovate. They can provide plausible inroads to understanding industry variation in innovation. And appropriability can in part be mapped to institutional features, including intellectual property and market structure (which becomes a potentially malleable institutional feature through antitrust policy and other regulatory mechanisms). In part because such policy features can be revised, this lens on industry variation and laggard sectors seems to be a first-order issue for research.

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suggests that the entry incentives are substantial, though of course the counterfactual market structures are not observed, and the causal effect of the market structure remains unclear.

13.5.2 Institutions and Basic Research

Basic research can play important roles in advancing marketplace innovations (e.g., Bush 1945), yet the payoffs are often indirect, with market value found in distant and often unexpected downstream applications (e.g., Ahmadpoor and Jones 2017; Azoulay, Graff Zivin, and Li 2019). Basic research thus exhibits another form of the appropriability problem, where virtually all the market returns to basic research are in its spillovers and cannot easily be captured by the researcher. Institutions such as the NIH and the National Science Foundation (NSF) can then play key roles in supporting basic research. Specifically, these institutions implement a policy model in which funding comes ex ante, through grants, rather than ex post, through some market appropriation mechanism.

From an industry point of view, public investment in basic research can be regarded as opening up new technological opportunities. One may then ask whether part of the industry variation in innovation follows from differential public investment in upstream basic research. Bruce and de Figueiredo (chapter 9, this volume) examine the allocation of federal research personnel and R&D expenditures across US executive branch agencies. R&D expenditures are largest in the Department of Defense, followed by Health and Human Services, with substantially lower R&D expenditure by several other agencies, including NASA, the Department of Energy, and NSF, and comparatively tiny R&D expenditure by the remaining agencies. Outside the Department of Defense, US government research funding is heavily tilted toward biomedicine through the NIH, which accounts for 44 percent of federal research funding.[11] NIH-sponsored research is often directly used by the private sector in developing new medicines and with high returns (e.g., Azoulay, Graff Zivin, and Li 2019). The opportunities this publicly funded research provides might then further help explain the high private sector R&D rates in pharmaceuticals and medicines (see table 13.1). By contrast with the biomedical sciences, we see much less government-supported basic research in other fields. For example, the R&D funding for the NIH is approximately 6 times, 36 times, and 144 times larger, respectively, than that for the NSF, Department of Transportation, and Department of Education.

Explaining the low rate of innovation in some sectors through "missing" basic research would be speculative as a primary explanation, but increasing funding for basic research should facilitate progress. And it is striking how little government-funded research occurs for key sectors of the economy. Take education, which is a fundamental force for increasing labor productivity, a key input to the innovative workforce, and a mechanism for intergenerational mobility and individual opportunity (e.g., Biasi, Deming, and

11. This measure is R&D funding to the Department of Health and Human Services (largely NIH) in FY2018, which shows similar tendencies in other years (Sargent 2020).

Moser, chapter 12, this volume; Bell et al. 2019; Card 2001; Hendricks and Schoellman 2018; B. Jones 2014). Yet education is the target of little public R&D. As another example, transportation and warehousing is a larger sector than pharmaceutical and medicines, yet it sees much less federally supported R&D. And in health, basic research in biomedicine is substantial and mirrored by enormously high rates of private-sector R&D, yet R&D targeting the provision of health services in hospitals and nursing homes—a much larger source of expenditure—seems almost absent by comparison.

Another example is energy research, where US federal support is more substantial than in many areas but still small compared to biomedical research. Beyond the social returns logic that applies to supporting basic research in general (e.g., B. Jones and Summers 2020; Stephan 1996), energy generation also calls for public support in other dimensions. First, the private sector will have difficulty marshaling resources for technology areas with substantial uncertainty over success and extraordinary fixed costs for innovation attempts. Nuclear fusion research, both for its high fixed costs and exploratory nature, then naturally relies on public support. Second, energy markets face an additional externality through fossil fuels and climate change, which suggests an even greater importance of basic research in this sector, in this case to advance alternative energy production opportunities. Expanding publicly supported research through the Department of Energy or other institutions thus has a natural logic and may be critical for confronting potentially large damages from climate change (e.g., Acemoglu et al. 2016; Dell, Jones, and Olken 2014).

For sectors that see little basic research support, it may be that basic research and private sector R&D are both low due to limited opportunity. For example, perhaps fundamental technological opportunity factors explain the lack of innovative investment in education or health services. Yet it would be hard to argue that education services or health services in the US could not be improved. The US lags many advanced economics in educational comparisons (e.g., Schleicher 2019). And the US spends twice the share of its GDP on health compared to other advanced economies, even as US citizens live substantially shorter lives.[12] One imagines that research to explain these problems and provide solutions could be endeavors with very high returns.

13.5.3 Institutions and Demand

Government institutions can also play roles on the demand side. Whereas basic research can be seen as part of a "technology push" mechanism, government can also create "demand pull" mechanisms. This can occur through

12. The US spent 17 percent of GDP on health in 2019, while the average across OECD countries was 8.8 percent (see OECD Health Statistics 2020, http://www.oecd.org/els/health-systems/health-data.htm).

direct buyer mechanisms (e.g., advanced purchase commitments) or through indirect mechanisms (e.g., tax credits for adopting specific new technologies). Governments can also play a role in certification, reducing buyer uncertainty.

As examples of demand pull policies, one can return to the energy sector, where many policies may have been motivated by direct considerations of negative externalities (from acid rain to greenhouse gases) but where adjusting demand for specific technologies also changes innovation incentives. Notably, for directional technology considerations, broad innovation institutions don't really help: a fossil-fuel innovation (e.g., fracking) can take advantage of patent law or research tax credits just as a clean energy innovation can. Shifting innovation toward technologies with milder negative externalities then requires more specific interventions to tilt innovation effort and incentives (Popp et al., chapter 4, this volume). One approach might be a carbon tax or quota system that asymmetrically raises the price of the more polluting technology. One can also direct energy production technologies with installation credits (e.g., the US Production Tax Credit for wind energy), direct buyer incentives (e.g., the Qualified Plug-In Electric Drive Motor Vehicle Tax Credit), or regulatory mandates (e.g., CAFE standards for automobile efficiency). These approaches are distinct from and can complement technology push approaches.

Institutions can also play first-order roles in certification, working on the uncertainty dimension of demand. Institutional intervention may be especially important where product and service salience is an issue. As discussed above, the FDA helps prove that new drugs are effective and safe. Reducing buyer uncertainty in this way may then be critical for elevating incentives to engage in drug R&D. The education sector appears again here, as a counterexample. While the US Department of Education has implemented the "What Works Clearinghouse" to collect and publicize information about rigorous assessments of innovations, there remains little systematic effort (or requirement) to engage in rigorous assessment of education tools (Chatterji and Jones 2012). One may then observe that many school systems invest in computers, tablets, and software tools but with little or no evidence that these are superior tools for children's learning (Biasi, Deming, and Moser, chapter 12, this volume). The education sector might be well served by the advent of institutions similar to the FDA, providing pathways for innovators to prove the quality of their new products and services. Rigorous certification can facilitate innovative entry and help schools and school systems adopt effective innovations.

13.5.4 Institutions and Scalability

As discussed above, scalability can be a key attractor for innovative investment. The enormous innovative effort and venture capital orientation toward information services seem to hinge on this logic, where new digital goods can scale cheaply, rapidly, and widely to reach new customers. While scalability in digitization depends critically on technology fundamentals, in many contexts, institutional and regulatory mechanisms also seem first order.

For example, health services embed privacy regulations that can inhibit data sharing. Such privacy regulations are well meaning in their own terms, but they also constrain the ability to innovate in health services through information sharing—innovations that could not only reduce costs but also create health benefits (e.g., by reducing diagnostic and treatment errors). Basic information about prices and outcomes is also hard for would-be innovators to ascertain. The balkanized market structure, complex regulatory layers, and intermixture of public and private insurers further inhibits scalability, and the US health system in the context of the COVID-19 pandemic has betrayed further weaknesses in data collection, testing, and coordination for patient care. By contrast, standard-setting organizations in the IT space have developed extremely successful interoperability protocols. The opportunity in health services for improvement seems vast.

Education services also face scalability challenges. Privacy regulations for students, which are again well meaning, can limit the collection of empirical evidence and the ability to assess educational innovations. State and local regulatory variation, and resource differences, further inhibit scalability. With thousands of different school districts, different views on teaching objectives, and weak evidence, selling new products depends enormously on a business's salesforce and its network of relationships with school districts. The Common Core State Standards Initiative may then be important not just for raising standards but also for innovation: It creates high-scale targets for pedagogical innovators. This standard setting effort has faced headwinds, however, and efforts at rigorous evaluations of education tools remain much further behind (Chatterji and Jones 2012).

As a notable contrast, the advance of ridesharing (e.g., Uber) and homestay markets (e.g., Airbnb) developed in the face of existing municipal taxi and hotel regulations. As business models that stood somewhat outside existing regulations, they were able to scale rapidly. Health and education services appear to face stricter restrictions that are hard for innovators to overcome—and an Uber-like approach of asking for forgiveness rather than permission seems less plausible. This suggests that conscious, ex ante regulatory reform and standard setting may be essential for allowing scalability and encouraging innovation. To the extent that regulations inhibiting scalability have benefits (e.g., for safety or privacy), participatory political processes can allow for greater care in how different dimensions of social welfare are balanced.

13.6 Conclusion

The story of growth in advanced economies like the US is one of aggregate steadiness overlaying massive cross-industry differences. This chapter, in tandem with the other chapters in this book, assesses the enormous variation in innovation across industries and presents a range of explanations. The issues at the sectoral level are high stakes. For one, the aggregate steadiness in economic growth has recently met headwinds, with the US economy entering an apparently sustained productivity growth slowdown. This slowdown becomes a sector-level issue not only in the obvious sense that macro outcomes are constructed from sectoral outcomes, but also more acutely because of the dynamics in sectoral GDP shares. Taking the perspective of a Baumol cost disease, the sectors that fail to progress end up occupying greater shares of GDP. Failures to advance these sectors can then become an economic albatross, calling into question the potential for future growth.

Lagging sectors are also high stakes because they directly limit progress at key challenges. One example is innovation in the energy sector and the capacity to avoid damages from climate change. Other examples are education and health services. Education may the greatest of all general-purpose technologies in the sense that it creates human capital, a key input to further innovation across the economy. Education also speaks to inequality, where failure to advance the quality of educational services across the economy undermines individual opportunity. Health services in the US meanwhile manage to be extraordinarily expensive by international comparisons even as the US population faces substantially lower life expectancy.

To assess and organize reasons for the large variation in innovative effort and success across sectors, in this chapter, I have used a three-part framework emphasizing demand, supply, and institutions. Plausibly strong forces exist in each dimension. However, whereas forces rooted in fundamental preferences and natural laws may be important, institutional forces are more elastic to change and therefore of more practical relevance. In this chapter, I have therefore highlighted some institutional roles in furthering innovation. The emphasis has been on institutional features that vary across sectors, from basic research support to regulation to appropriability regimes. While the analysis is necessarily incomplete, the frameworks and sectoral examples suggest fruitful opportunities for policy. Assessing policy options in detail and continuing to unpack the sources of cross-sector innovation differences are critical areas for future research.

Ultimately, innovation comes down to the opportunities and incentives facing individuals, firms, and investors. Naturally, innovative agents gravitate toward sectors with larger opportunities, which today appear especially in biomedicine and IT. But from a social progress point of view, innovators, policymakers, and scholars need to think not just about "the room where it happens" but also about "the rooms where it doesn't happen." If the dearth of innovative activity in some industries is due to a fundamental lack of technological opportunities, then the current allocation of effort across sectors may be appropriate. But innovation is an environment with large spillovers and market failures, and uneven institutions, so that there is little reason to think that we have an efficient allocation. The overarching observation in this chapter is that we need to pay substantial policy and research attention to these "rooms where it doesn't happen," because they matter, and because there are many policy instruments that could elevate innovation and attack the essential problems that these sectors pose.

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