Real Effects of Academic Research Revisited

Preliminary Draft for Discussion

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Abstract

This Chapter surveys the findings of social science research on the contribution of universities to innovation and economic growth, both locally/regionally and globally. In the last several decades research has demonstrated universities' causal effects through the mechanisms of knowledge creation, education and training of students and technology transfer/entrepreneurship. The Chapter summarizes how the literature has studied these mechanisms in different disciplines and industrial sectors, and in different countries. The depth and breadth of understanding have been advanced by new microdata and new methods of linking data across inventions, scientists and institutions, and by application of methods from network science. These findings have implications for public policy to foster innovation both regionally and globally.

1. Introduction

At a deep level over long time frames, it is obvious that universities play fundamental and crucial roles underpinning innovation. They perform a large fraction of all basic research, and they are the preponderant institution in which people receive advanced education and training across the spectrum of human knowledge. The thought experiment of a world without universities is not interesting. We need them.

Despite their obvious value, there emerged in the last quarter of the 20th century increased attention to understanding the specific pathways and mechanisms by which the generation and transmission of knowledge that occurs at universities leads to specific technological and economic benefits, particularly in the relatively short run. This increased attention was motivated in part by debates over the magnitude of public resources that universities should receive, but also by a concern that greater technological and economic benefit could come from the given level of resources under different policy and institutional practices. Greater attention to achieving the maximal possible return for the public investment in universities can also be seen as a natural evolution from the post-WWII period, in which resources devoted to universities grew dramatically.

Thus, we have seen over the last 50 years significant growth in social science research on the pathways and mechanisms by which universities affect innovation and improve public welfare. At the same time, academics as individuals and universities as institutions have undertaken deliberate, sustained efforts to increase these broad social impacts. While this evolution began first and has been particularly pronounced in the case of the United States, the rest of the world has followed suit, sometimes in deliberate imitation of U.S. policies and practices, and sometimes with different approaches.

Jaffe (1989) was an early attempt to take methods that economists had used to study innovation in firms, and apply those methods to document the innovation impact of universities. In this Chapter, we seek to review the large volume of subsequent work, to assess critically where we now stand in terms of understanding this system, to elucidate the implications of this understanding for public policy, and to suggest areas where further research is likely to be fruitful.

1.1 The Historical Origins of Academic Research and Commercialization

Nelson and Rosenberg (1994) identify what we posit to be the first two of four structural transformations in the evolution of university research. The first involved establishing land-grant universities and institutionalizing the applied sciences, and the second involved the professionalization of the sciences, which created a division of labor between basic research undertaken in a university environment, and applied tasks which transitioned out of universities and into firms and vocational schools (Nelson and Rosenberg 1994). While their historical analysis of American university research sought to address ongoing concerns that university research was distancing itself too much from basic research, we recount history here for a different purpose in revealing how American universities developed their pragmatic orientation toward industrial needs. This orientation established the institutional foundation for the commercialization mechanisms that emerged in later decades, as documented by the extensive literature analyzed throughout this chapter. European universities, meanwhile, followed different trajectories that produced their distinct commercialization patterns, which will be discussed in detail later in this chapter.

Part 1: Land-Grants and the Institutionalization of Applied Science

The establishment of land-grant universities and the institutionalization of applied sciences represented a distinctly American approach to higher education, one rooted in pragmatic values that predated the formal university system itself. This pragmatic orientation, first documented by French diplomat Alexis de Tocqueville during his 1831 American visit. Tocqueville observed that Americans displayed “a clear, free, original, and inventive power of mind' but devoted little time to 'the theoretical and abstract portion of human knowledge.” According to his observations, Americans pursued science for immediate practical purposes, valuing “every new method which leads by a shorter road to wealth, every machine which spares labor, every instrument which diminishes the cost of production” (Tocqueville 2010).

Yet this approach had been institutionally codified decades before Tocqueville's observations through the Northwest Ordinance of 1787, which declared education imperative to "good government" and required each municipality to allocate land for public schools (The U.S. National Archives and Records Administration, 2022). By the 1850s, Congressman Justin Morrill of Vermont recognized that this educational foundation could use an extension into higher education, particularly as westward migration left settlers without access to universities located in the East, and traditional colleges that taught Latin and philosophy failed to meet industrialization's demands. Military academies like West Point offered some engineering training but proved inadequate for civilian needs.

Morrill's solution, a land-grant college bill first introduced in 1857 and vetoed by President Buchanan in 1859, finally succeeded during the Civil War when demands for technical training, agricultural production, and industrial capacity became urgent. President Lincoln signed the Morrill Act on July 2, 1862 (Clinger, n.d.), granting each state 30,000 acres per congressional representative to fund colleges dedicated to agriculture, the mechanical arts (i.e., engineering), and military tactics (United States Senate, n.d.). This legislation fundamentally altered American higher education by creating universities explicitly devoted to practical problems while maintaining state-level control. The land-grant universities became natural links to local economic needs, sustained by their decentralized revenue model that required attracting students and charging tuition (Nelson and Rosenberg 1994). The Hatch Act of 1887 further aligned academic research with industrial needs by establishing agricultural experiment stations and providing the first targeted federal research funding (Agriculture, 2025).

Part 2: The Professionalization of Science and a Division in Labor

The emergence of formal disciplines in these universities along with decades of pedagogical iteration shaped to meet localized needs gave way to what Nelson and Rosenberg deemed to be a second structural transformation, the professionalization of science met with a division in labor. This occurred along two lines. First, through a division of labor sparked by industrial maturation and a growing demand for basic research; and second, through a natural separation that saw universities focus on fundamental research while vocational schools and firms absorbed practical applications (Nelson and Rosenberg 1994). The initial growth manifested through highly localized specialization. Wisconsin developed dairy science programs for cheese production, Iowa taught food preservation techniques essential for harsh winters, Illinois created railway engineering degrees as Chicago became the nation's rail hub, and Michigan focused on lumber and furniture manufacturing to exploit its vast forests. The Midwest became the primary laboratory for this experiment, where new universities unencumbered by classical traditions debated pedagogical approaches to science. By the 1890s, industrial research laboratories like General Electric (1900), DuPont (1903), and Bell Labs (1925) demanded engineers trained in scientific principles rather than practical applications, transforming land-grant institutions where engineering enrollment surpassed agriculture by 1900 as universities shifted from shop work to laboratory instruction (Nienkamp 2010).

Within two decades, American higher education had settled into distinct institutional roles, with universities claiming basic research and professional training while ceding applied development and commercial exploitation to industry. This arrangement benefited both parties. Universities avoided commercial pressures that could compromise academic freedom while firms gained access to trained personnel without maintaining expensive basic research facilities (Nelson and Rosenberg 1994), creating the foundation for twentieth-century American technological development.

Part 3: The Commercialization of Research and the First University Patent

Building on Nelson and Rosenberg's historical narrative, we argue that a third transformation of university research arose with the university patent itself, and the subsequent formalization of mechanisms and incentives to commercially exploit university research. This transformation began tentatively in 1912 when Frederick Cottrell, a Berkeley chemist, established Research Corporation, a third-party organization designed to handle university patents and insulate universities from the business aspects of patent management. Cottrell's creation of Research Corporation reflected widespread academic ambivalence toward treating knowledge as exclusionary property, which conflicted with existing commitments to open science. As Sampat (2006) documents, most major universities before 1980 either avoided patenting altogether or outsourced patent management to Research Corporation, which by 1937 had signed its first formal agreement with MIT to handle invention disclosures while shielding the institution from potential "political embarrassment." Some universities created alternative models, notably Harry

Steenbock's vitamin D irradiation process at Wisconsin in 1924, which led to the Wisconsin Alumni Research Foundation (WARF), establishing a pattern of affiliated but legally separate foundations. Columbia's policy explicitly stated that holding patents was "not deemed within the sphere of the University's scholarly objectives," reflecting the prevailing academic culture that viewed commercial activities as fundamentally at odds with scholarly mission (Sampat 2006).

This arms-length relationship with commercialization began eroding in the 1970s due to what Sampat (2006) identifies as three converging forces: increased postwar growth of "use-oriented basic research," declining federal funding that made patent income attractive, and preliminary changes in government patent policy. The transformation accelerated dramatically with the Bayh-Dole Act of 1980, which "swept away the patchwork of individual agency-controlled" patent agreements and granted universities uniform rights to patents from federally funded research, a response to economic stagnation and growing concerns over American competitiveness (Sampat 2006). The Act spurred the establishment of Technology Transfer Offices that became institutionalized within nearly every major research university, creating formal mechanisms for universities to manage and profit from intellectual property.

Part 4: Beyond the Hard Sciences: Shifts and Advances Towards Automation, Artificial Intelligence, and the Data-Driven Economy

The fourth transformation, which we argue is currently underway and accelerating since the early 2000s, reflects the pervasive influence of digitalization, artificial intelligence, and computational methods across all disciplines of research. Machine learning algorithms now support hypothesis generation in drug discovery and materials science, while computational approaches enable analysis of massive datasets that would be impossible through traditional methods. This transformation has spawned new forms of university-industry collaboration that center on data access and algorithmic expertise rather than traditional laboratory-to-market channels, with companies partnering with universities not for physical inventions but for computational models, training datasets, and algorithmic innovations. It challenges existing institutional arrangements in multiple ways including the open-source movement compared with traditional intellectual property frameworks, digital collaboration transcends geographic boundaries that once defined university-industry partnerships, and the nature of research outputs increasingly shifts from patents and publications to trained models, algorithms, and curated datasets that existing metrics fail to adequately capture. Unlike the previous three transformations that largely maintained or reinforced the geographic clustering of innovation, this digital transformation potentially decouples innovation from physical proximity, raising broader questions about how universities will maintain their role as anchors of regional innovation ecosystems. The implications of this transformation for university governance, research evaluation, and the measurement of innovation impact remain actively contested and will be explored throughout this chapter.

2. Analytical Issues

2.1 Creation of knowledge and spillovers

A basic premise of this conference is that innovation is a key driver of improvements in prosperity and well-being over time. Analytically, this role for innovation derives from the *spillovers* generated by knowledge (i.e., benefits derived from knowledge that accrue to people or organizations beyond those that created it). The magnitude of these spillovers is dependent on the *diffusion* of knowledge, because widespread benefits from any given chunk of knowledge are dependent on that knowledge being widely available and usable.

Universities are institutions dedicated to the creation and transmission of knowledge. Indeed, they are arguably the most important category of institutions responsible for the creation and transmission of knowledge responsible for the ongoing innovation that drives economic growth and other improvements in the human condition.

Consider first the scale of resources devoted to knowledge creation through formal research. U.S. businesses perform about $700 million of 'research' annually; universities and related non-profits perform about $100 million in research. But there are several important reasons why the overall contribution of universities to spillovers is likely greater than that of firms

The incentives facing firms are to do everything they can to prevent the knowledge that they create from 'spilling' out, while universities are in the business of disseminating knowledge. In addition to the noted research expenditures, universities spend about $200 million on instruction (National Center for Education Statistics, 2023), and engage in a variety of formal and informal activities such as scholarly publication, technology transfer and consulting that foster the dissemination of both new and previously discovered knowledge. Indeed, from a broad social and historical perspective we can think of universities as the primary social institution dedicated to the maintenance, curation and transmission of knowledge, old and new. The flip side of the spillover phenomenon is that innovation is a cumulative process, with new ideas always using and then building on the extant stock of available knowledge. If this stock were not maintained, organized and transmitted to successive generations of innovators, the process would be greatly hindered.

Further, the preponderance of firm spending on research is for applied research and development, while the preponderance of university spending is for 'basic' research; as a result, universities overall perform the majority of basic research (about $70 million, compared to about $50 million at firms).[1] Basic research is defined as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts" (National Center for Science and Engineering Statistics, 2025).

Akcigit et al. (2020) provide quantitative evidence for this basic-applied research relationship through a general equilibrium model distinguishing spillovers across research types. Their findings reveal that approximately 90% of basic research benefits are not internalized by the originating firms, with these spillovers increasing applied research productivity by 60% (Akcigit et al. 2021). This generates substantial welfare improvements through public basic research spending, and the model demonstrates that basic research spillovers create complementary effects with other innovation policies: R&D tax credits for firms become more effective when combined with public basic research funding, as the spillovers simultaneously increase firms' R&D incentives and enhance the resulting applied research effectiveness.

The relationships among basic research, applied research, invention and innovation are subtle. Donald Stokes (2011) famously suggested two fundamental attributes of research: whether it seeks fundamental understanding of scientific facts and principles, and whether it seeks some practical use. "Pure" basic research in this formulation is characterized *only* by the first attribute, and "pure" applied research is characterized only by the second. Stokes used the work of Niels Bohr as the prototype of pure basic research and that of Thomas Edison as the prototype of the latter. But Stokes' important insight that there is a third category, which he called "use-inspired basic research", which he associated with Louis Pasteur. Pasteur was motivated by his desire to

[1] All of the above research expenditure numbers are based on the most recent reported data, for 2022 (NCES, 2024). Totals given above for universities include modest amounts reported for 'Non-profit organizations', the largest of which are research centers affiliated with universities. Research is also performed by government, about $70 million total and 10 million basic in 2022.

protect people from disease, but this motivation led him to discover and demonstrate previously unknown fundamental biological processes. Stokes argued that much basic research in the modern world takes this form, so that new understanding of basic science and solution of real-world problems go hand in hand. This kind be seen in many aspects of current university research, from fundamental work on how viruses and bacteria interact contributing CRISPR technology, to quantum physics that may eventually give us quantum computing and communications (Stokes 1997).

Stokes' observation about use-motivated basic research is useful for understanding the distinction between the motivation underlying research and its potential consequences. But regardless of motivation, basic research overall generates large and long-lasting spillovers, and thereby lies at the heart of universities' contributions to innovation and well-being. While John Maynard Keynes' quip about practical men being the slaves of defunct economists is mostly seen as a joke, many practical people are indeed dependent on the work of forgotten scientists.

2.2 Causality

2.2.1 The causality problem with respect to impacts of university research

As discussed below, it is easy to show that cities and regions with more university research expenditure have more innovation and more economic growth. For many people who live in or think about universities and innovation, the notion that nearby innovation and its benefits are at least partially due to university research is a no-brainer. But social scientists know that correlation does not necessarily imply causality,[2] even where causation seem obvious we seek ways to measure rigorously the causal effects.

[2] https://imgs.xkcd.com/comics/correlation.png

Before turning to methods for making reliable causal inferences, it is useful to go beyond the generic 'correlation is not causality' idea and think about the underlying reasons why university research and regional innovation and growth might be correlated even if university research had no effect on innovation.

1. Exogenous factors affect both university location/size and regional innovation/growth. The reasons why cities are where they are and why they thrive there may, to some extent, affect universities as well. E.g., the weather in (what we now call) Silicon Valley is lovely. That might attract smart and creative people in general, thereby facilitating both universities and innovative firms to flourish, even if the former did not influence the latter.

2. City/regional success—coming about for whatever reasons—might then foster university success. This effect could either be general (e.g. wealthy cities have nicer parks and better schools, which attracts better university faculty) or specific (successful innovative firms generate knowledge spillovers that foster the success of nearby university researchers).

3. Universities may have causal effects that do not operate through the mechanism of research spillovers. Harvard has amazing art museums and Harvard Yard is a lovely (more or less) open public space. These amenities might attract firms and their employees to locate in Cambridge, independent of any direct effect of Harvard research on the firms' innovative activities.

4. The causal effect of knowledge spillovers, if real, may have indirect or second-order effects that are conceptually distinct from the direct spillover effect. In particular, knowledge spillovers may induce firms to move near universities, which in and of itself may have effects on innovation and economic growth that are not a (direct) consequence of the knowledge spillovers themselves.

Note that the role of these theoretical possibilities relative to the university-research-knowledge-spillovers-causal story is not either/or. In general, all of these things can and do happen to some extent. And at least some of these alternative mechanisms are themselves implausible if there were, in fact, literally no local spillovers from universities. But our research goal is not merely to reject the 'null' hypothesis of no effect. We would like to measure the magnitude of the causal effect, and for that goal the operation of these other mechanisms matters. For example, the growth of a major private sector pharmaceutical cluster in Cambridge and Boston is surely the result, in part, of the research success of Harvard and MIT. But that for-profit activity now surely also feeds back and benefits the universities. As we try to extract the magnitude of the university research spillover effect from data on university and firm activities, we may over-estimate its magnitude if we do not consider that feedback effect.

This discussion has focused on the impact of university knowledge spillovers on nearby innovation and growth. Because of the idiosyncrasy and complexity of geographic relationships, and the significant impacts of agents moving from one region to another, the challenges to measuring causal effects at this level have received much attention. It can also be shown for the world as a whole that changes in university research spending in different scientific areas are associated, with a lag, with changes in innovation in related technology areas. Here the challenge to causality falls mainly in the possibility that exogenous changes in technological opportunity or intellectual/social interest might drive both.

2.2.2 Solutions to the causality problem

It is common to think about the causality problem in terms of its mirror image, the endogeneity problem. That is, if we are trying to infer the effect of some factor X on some outcome Y, correlation-based measures of that effect are biased if X is itself determined endogenously within the larger system containing X and Y. All solutions to this problem rely, in some way, on finding exogenous factors Z that affect X but not Y, and using this exogenous variation in X to estimate its effect on Y in a way that is free from the endogeneity bias.

The classical way of implementing this idea is instrumental variable estimation (IV). Traditional IV estimation relies on identifying a variable in the data that, in our model of the world, affects X but does not affect Y directly (i.e. it affects Y *only* because it affects X and X affects Y). We call that variable an ‘instrument’, and we then identify the portion of the variation in X that is associated with variation in the instrument, and we use only that conditional variation in X when we measure its association with Y. For example, in the original 'Real Effects' paper, the effect of university research on corporate patents in the same state was estimated using state population and the count of universities in the state as instruments to purge university research of its endogeneity as we estimated its effect on corporate patenting.

That paper could probably not get published today. In the last decade of the 20^{th} century, economics underwent a major causality revolution, such that much stricter standards are now applied to establishing the exogeneity of the instruments used to purge variables whose causal effects we seek to measure of their endogeneity. Roughly speaking, under the old approach, a variable could be used as an instrument if a plausible argument could be made that it didn't affect Y. But these instruments were often nonetheless in a general way endogenous parts of the larger system containing X and Y. For example, while there is no obvious mechanism by which state population affects corporate patenting in that state, population is still endogenous in a general way, depending as it does on fertility and migration, and affecting all kinds of other regional variables such as construction activity. Thus, with this kind of instrument, one can never really establish the validity of the instrument on a solid foundation.

Under the new approach, instead of looking for *variables* in the data that plausibly affect X but not Y, we look for discrete, identifiable *events* that affect X, and have the property that some portion of the observations in the data were affected by these events, and others weren't. In this way, observational data can be used in a way that makes it much like experimental data: we view the exogenous conditioning event as a "treatment" that was applied to some agents and not others, and we measure the 'treatment effect' by comparing the treated group to the untreated group.

As the causality revolution has proceeded, people have become more and more creative in finding exogenous conditioning events. As discussed below, an important strand of research on the effects of university funding uses variations in funding levels driven by political events as the exogenous driver. Combining multiple political events generates variations in funding levels that are a lot like old-fashioned instruments. The fundamental difference comes down to how the validity of instruments is argued. Under the old regime, instruments were kind of presumed valid in the absence of obvious direct linkages to the dependent variable. Under the new approach, the focus is on the specific *process* that generated the asserted exogenous variation, and the burden is on the researcher to demonstrated that the process was driven by exogenous variation.

The causality revolution been extremely valuable to research on the impacts of university research; as discussed below we now have a number of quite strong confirmations of the importance of the spillover effects. But finding ‘clean’ exogenous events that drive these processes is dependent on luck and hard work; there are many questions we would like to answer for which there is no obvious natural experiment. Particularly where we have new questions and/or new data, we may see intriguing correlations that suggest a causal effect with no obvious factors that likely would cause a large endogeneity bias. While we need to be careful not to over-interpret such findings, they do tell us something about the world even if they might be hard to get published. Conversely, because good natural experiments are rare, the quest for settings with clean causality sometimes takes researchers to settings that are far afield contextually or historically, with the result that we get clean causal results, but it’s hard to know if they are applicable to the time and context we most care about. Hence we may learn most from a balanced approached, in which clean causality is viewed as desirable but not the only determinant of whether research is useful.

2.3 Measurement Issues

“Real Effects” in the title of the 1989 paper was a tongue-in-cheek takeoff on what was at the time a burgeoning macro/finance literature documenting real—meaning non-financial—effects of financial actions. In plain English, the obvious effects of university activities (i.e., a deeper understanding of the world we live in and educated graduates), are of course quite real. But university boosters and alumni magazines have for a long time claimed broader benefits in terms of economic growth and broader well-being. Our challenge is to quantify the magnitude of universities’ effect on these broader goals.

For this purpose it is useful to distinguish ‘outputs’ and ‘outcomes’ (Jaffe 1998; Hall and Jaffe 2018). The outputs of universities are its direct consequences: new knowledge and students with more knowledge in their heads. The outcomes are the ultimate social goals that these outputs facilitate: improved general, widespread understanding of ideas and universal laws of the natural universe and social systems; higher societal income and wealth; improved health; cleaner environment. Some of these benefits accrue to the universities, their faculty and their students. That’s a good thing, but for policy purposes we are more interested in the spillovers, i.e. the benefits that flow to parties other than the university, its employees and customers.

These ultimate outcomes arrive with lags that are often long and always of uncertain duration, and ultimately result from complex interactions of university outputs with many other factors. Thus tracing the path from university activities to ultimate outcomes is often quite difficult. For this reason, research often focuses on *intermediate outcomes*. An intermediate outcome is something that is not desired for its own sake, but which represents an observable step along a pathway to a desirable outcome. While we often think of innovation as privately and socially valuable, that value fundamentally arises because innovations can make us richer, healthier, etc., so conceptually it is an intermediate outcome.

The research project can thus be conceptualized as the effort to understand the relationships among university inputs, outputs, intermediate outcomes and ultimate outcomes. That takes us to the question of how to measure these things. How do we know if one university or one field or one year is generating a lot of new knowledge or not very much? How do we know if Boston is innovating more or less than Silicon Valley? These are analytically deep and difficult issues that we will not tackle here. We will adopt the approach of the empirical literature, which is to identify proxies or indicators that we believe usefully capture differences and changes in the magnitude of the underlying phenomena.[3]

Because we must use proxies for the variables of interest, much research effort and academic writing is devoted to debating the validity of different proxies.[4] Some of this is just a matter of careful practice. For example, citations accumulate over time, and citation practices and journal structures make citation rates higher across the board in some fields than others. For these reasons, when using citation-weighted patents or papers as output measures, the citation counts should always be normalized by dividing the count for each item by the average number of citations received by items issued at the same time in the given field.

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[3] In principle, an indicator is a measurement or statistic that is designed to capture a given phenomenon, e.g. the BLS Unemployment Rate is an indicator of the fraction of the population without work. A proxy is a stand-in that we know is not the phenomenon of interest, but we think is correlated with it, e.g. the number of Google searches for some keyword can be a proxy for the current overall level of interest in a topic. But because knowledge and innovation are on some level inherently unmeasurable directly, this distinction is hard to make. It is hard to say whether patent counts are an indicator of invention or a proxy for invention, and the answer depends to some extent on how one defines invention.

[4] While indicators and proxies can each be well or poorly designed, 'proxy' seems subjectively to better convey our underlying uncertainty about how well we are measuring the phenomenon of interest, so we utilize that term.

But other issues are harder to resolve, i.e. what does it really mean for papers to more highly cited? More important? Greater impact? More famous author? Better publicity? And the limitations of the available proxy make certain particular kinds of questions hard to answer. How can we tell if the overall rate of scientific or technological progress is speeding up or slowing down? We often use citation-related metrics to measure the significance of particular outputs. We just said that you can only meaningfully compare citation rates *within* a given field and time period. This makes it very hard to say whether today's science or today's inventions are better or worse than those of previous times.

The limitations of available proxies can be mitigated by the use of multiple proxies. If distinct proxies, based on different kinds of data, point towards the same conclusions, they are probably valid conclusions. More generally, the limitations of available proxies do not mean that nothing can be learned, but they do mean that caution is called for in interpretation and generalization.

2.4 Geographic Scope of Effects

As noted, universities simultaneously affect the city and region in which they lie, and the world as a whole. In terms of spillovers, there are two conflicting forces at work. Knowledge is a public good; in and of itself this means that knowledge created at a given location can be used anywhere in the world. But the process of knowledge diffusion is not frictionless. At a practical level, people and institutions near a knowledge creator are more likely to learn about the new knowledge, learn about it sooner, and be better able to use it effectively. The dynamic interplay of these forces affects many aspects of the university input/output/intermediate outcome/ultimate outcome process that we wish to study.

First, what constitutes an outcome is different at different scales. Universities cause firms and talented individuals to relocate to university neighborhoods and regions. From the perspective of the university region, such relocation is a (mostly) desirable intermediate outcome, because it leads to increased regional economic growth. But from the global perspective, there's no real outcome: the total amount of economic activity has not changed, it's just been rearranged.

This distinction in turn has policy implications. Drawing in firms and talented people is a regional policy objective that might be pursued by supporting university activities. But for the world as a whole this is a zero-sum game. Even for individual countries, particularly large ones, this may be a largely zero-sum game, as the relocation may come mostly within a given country.

Finally, research on the outcomes of university research seeks to understand the mechanisms by which these outcomes come about. These mechanisms can be thought of as pathways that intentionally or unintentionally operate to overcome the frictions that otherwise limit the diffusion of knowledge. Hence they are mediated by geography. This means that different mechanisms operate on different geographic scales, and given mechanisms are more or less effective at different scales. For these reasons, our summary in the next section of what is known about the impacts of knowledge, human capital and entrepreneurship is organized in part around the global/regional distinction.

3. Mechanisms of Impact

Throughout their existence, universities have been entrusted with different roles in society. Nowadays we tend to associate them with three fundamental missions that define their societal role. The first mission, education, is concerned with the systematic transmission of knowledge and the cultivation of intellectual capacities. This function extends beyond the mere dissemination of information; it seeks to foster critical thinking, analytical reasoning, and the ability to apply theoretical insights to practical contexts.

The second mission, research, is dedicated to the generation of new knowledge and the advancement of scientific, technological, and cultural frontiers. Universities house both fundamental and applied research, contributing to theoretical development while addressing complex societal challenges. This mission is intrinsically linked to education, as research-informed teaching not only aims to transfer state-of-the-art knowledge but also equips students with the skills necessary for inquiry and innovation.

Finally, the so-called “third mission” has emerged as an increasingly salient dimension of university activity, emphasizing engagement with society beyond the traditional domains of teaching and research. It encompasses a wide range of initiatives, including technology transfer and commercialization, cultural dissemination and outreach, and engagement with industry, government, and civil society.

These different missions reflect the different types of impact universities have on innovation and economic growth. While it would be possible to undertake documenting and understanding the impact of universities on innovation and well-being simply by trying to identify and trace spillovers from university activities in general, this would ignore the variety of mechanisms at play, and the fact that the policy consequences and opportunities with respect to facilitation or enhancement of the social benefits of university activities differ somewhat for these different mechanisms.

However, before discussing specific mechanisms, it is important to emphasize that just the ongoing day-to-day functioning of universities is a hugely important contributor to innovation and welfare. As we have emphasized, the welfare-enhancing impact of universities comes about because of spillovers. On a very fundamental level, spillovers come about through some kind of connection between one agent who knows something, and another agent who does not previously have that knowledge. Such connections can be entirely impersonal, such as the reading of a published work. But the evidence is overwhelming that personal interactions are very important to the overall diffusion of knowledge, and face-to-face interactions are particularly important. Whatever else they do, universities are a place where people meet people that they didn't know before. Students meet professors, professors meet students, students meet each other, professors meet visitors, and so forth. The meetings foster long-term relationships that constitute the backbone of the international knowledge transfer and innovation network.[5] Even before considering the specific impacts of university education, training and research undertakings, we can think of them as a kind of spillover infrastructure, whose very existence generates benefits through the constant flow of knowledge through the innovation network.

In this section, we organize our discussion of the evidence on university impacts and policy choices around three key mechanisms of impact, mirroring the three main missions of modern universities:

1. Creation of human capital;
2. Creation and dissemination of knowledge;
3. Commercialization and entrepreneurship.

The operation of each of these mechanisms is mediated by geography. We could think of these effects as radiating out from the university in a more or less continuous fashion, with the fastest and largest effects occurring right next door, and then effects diminishing gradually with distance from the university. There is some reality to such a description, but for both practical and policy-

[5] The majority of cross-national scholarly co-author pairs were physically co-located at some point in their careers (need citation).

motivated reasons, it is useful to think of the geographic modulation more categorically. That is, we will consider each of the mechanisms in terms of their local/regional effects, and also in terms of their global effects

In the remaining of the section, we will discuss the existing empirical evidence following the combination of these two elements – mechanisms and geography. This is not by any means an exhaustive nor a systematic review of the literature on the topic, but rather an overview and a synthesis of the most relevant themes and contributions in the area. It is important to note that the separation between the three mechanisms and their policy implications is not clear-cut, and often papers make contributions spanning more than one mechanism.

3.1 Creation of human capital

Universities' educational mission constitutes a cornerstone of their contribution to innovation and economic growth, primarily through the creation of human capital. From the perspective of endogenous growth theory (Romer 1990), human capital is not merely an input into production but a dynamic factor that enhances an economy's capacity for technological progress. The presence of some amount of university enrollment in the background of most inventors, innovators and entrepreneurs is so pervasive that it is very difficult to identify meaningful natural experiments that would capture the effect of such enrollment. By training students in advanced cognitive and technical skills, universities increase the stock of knowledge workers capable of generating and applying innovations. This process extends beyond the acquisition of codified knowledge; it involves the development of problem-solving abilities, adaptability, and absorptive capacity—attributes that enable individuals to integrate and exploit new technologies effectively.

Keith Pavitt's seminal work on the economics of technical change provides a critical lens for understanding the mechanisms through which education translates into innovation (Pavitt 1984). He argued that the economic usefulness of scientific and technical knowledge lies not only in its direct application to technology but also in the broader skill base it creates, which underpins firms' capacity to innovate across sectors. His taxonomy of innovation patterns highlighted that sectors differ in their reliance on science-based knowledge, yet all benefit from a workforce trained in analytical and research-oriented competencies. This insight reinforces the notion that universities' role in cultivating such competencies is foundational to systemic innovation capacity. Firm-level studies corroborate this view: the presence of highly educated employees, particularly those with postgraduate training, significantly increases the likelihood of successful product and process innovations (Kaiser et al. 2018) Similarly, Zucker, Darby, and Brewer (1998) demonstrated that the presence of "star scientists" in biotechnology significantly accelerated firm-level innovation and the emergence of regional clusters (Zucker et al. 1998).

At the local scale, graduate retention strengthens regional innovation systems through thicker skills supply, denser networks, and higher absorptive capacity in firms and public organizations. Large cross-country evidence shows that regions with stronger university presence and graduate stocks experience higher subsequent income growth, with positive spillovers to neighboring regions, consistent with localized knowledge diffusion (Valero and Van Reenen 2019). Within countries, human capital explains a large share of variation in regional income and establishment productivity, underscoring the centrality of skills for development (Gennaioli et al. 2013). Moretti (2004) further documented human capital externalities, showing that a 1% increase in the share of college graduates in a city raises wages for non-graduates by 1.6%, reflecting productivity gains from knowledge diffusion and learning-by-interacting mechanisms (Moretti

2004). At the same time, it is important to notice that the preference for graduates to stay in the same region as their *alma mater* (Stephan 2006; Dahl and Sorenson 2012) is a strong influence in the localized nature of spillovers from universities, as organizations located in proximity of higher education institutions will attract talent more easily than organizations located farther away.

At the global level, migration and mobility of graduates enable the circulation of tacit knowledge across borders, fostering innovation in both sending and receiving countries. It is well-established that immigrants to the U.S. are disproportionately represented among innovators and entrepreneurs, and many of these immigrants first come to the U.S. to enroll in a university (Amornsiripanitch et al. 2023). More generally, studies on international flows of university-educated individuals and academics show that mobility contributes to "brain circulation" rather than permanent loss, as mobile graduates often maintain research ties, engage in joint projects, and facilitate technology transfer between countries, also through return migration. For example, Fry (2023), shows that African scientists who have a stint as a visitor in a laboratory in a 'core' country, increase the productivity of *other* proximate African researchers after they return home (Fry 2023). These global spillovers are particularly significant in science-based sectors, aligning with Pavitt's observation that such industries depend heavily on the mobility of highly trained individuals for innovation.

3.2 Creation and dissemination of knowledge

Universities' research mission is a fundamental driver of innovation and long-term economic growth through the creation of new knowledge. Direct effects occur when universities produce scientific and technological outputs (such as publications and patents) that feed directly into industrial innovation. A famous example is the collaboration in the 1950s between Nobel Prize laureate Giulio Natta, a professor at the Polytechnic University of Milan, and Montecatini, a chemical company, which eventually led to the discovery of isotactic polypropylene. Mansfield estimated that between 11% and 15% of new industrial products in the United States could not have been developed without recent academic research, underscoring the tangible contribution of university-generated knowledge to technological progress (Mansfield 1991; 1995; 1998).

Literature in this area has benefited tremendously from large-scale efforts, both in the US and in Europe, aimed at measuring different aspects of innovation activities of firms, namely through the Community Innovation Survey (CIS) in Europe and the Carnegie Mellon Survey (CMS) in the U.S. These surveys represent two foundational efforts to measure innovation and knowledge flows, albeit with different scopes and methodological emphases. The CIS, launched in 1992 under the Oslo Manual framework, provides harmonized, cross-country data on innovation in European firms. It captures a broad range of innovation activities and systematically measures the importance of external knowledge sources, including universities and public research organizations, as well as cooperation patterns. By contrast, the CMS, conducted by Cohen, Nelson, and Walsh (1994), focused on U.S. manufacturing firms' R&D activities and their reliance on external knowledge sources (Cohen et al. 2002). Unlike CIS, which emphasizes the existence and intensity of linkages, CMS explored the mechanisms of knowledge transfer in depth. It asked firms to identify the channels through which they accessed academic research (such as publications, conferences, consulting, and hiring graduates) and to assess their relative importance. Beyond its direct findings, this paper has been highly influential in policy and academic debates about academic commercialization, challenging the notion that patenting and licensing are the primary avenues for universities to impact industry. By demonstrating that "public expressions of public research" (open publications, conferences and informal interactions) typically convey academic knowledge more effectively than patents do, it provided evidence that investing in open science channels and university–industry collaboration may yield greater innovation benefits than focusing narrowly on IP (Cohen et al. 2002). Empirical studies confirm similar patterns in Europe. For example, Scandura (2016) compares firms participating in collaborations with universities with propensity-score-matched similar firms that are not collaborating, measuring the effect of collaboration on R&D expenditure and share of R&D employees. She finds significant and persistent effects, with firms 3-5 years after the collaboration showing about 20% greater R&D expenditure per employee and about 3% higher share of R&D employees. Since expenditure grows so much more than employment, this suggests that collaboration raises the wages of R&D employees, implying some combination of rent capture by those employees and increased R&D staff quality.

Indirect effects from university research arise through knowledge spillovers, where research results diffuse beyond formal commercialization channels into the broader economy. These spillovers reflect the fact that scientific knowledge and methods can help firms in a number of activities, such as avoiding wasteful experimentation when working with complex technologies (Fleming and Sorenson 2004), increasing the productivity of applied research (Nelson 1959; Evenson and Kislev 1976), identifying and integrating external knowledge more efficiently (Cohen and Levinthal 1990; Gambardella 1995; Cockburn and Henderson 1998).

Since the seminal work of Jaffe (1989), economics of innovation literature has highlighted spillovers from universities as key sources in promoting firm innovation and performance (Hall et al. 2003). In particular, empirical studies have found that universities contribution to industrial innovation is greater the higher the quality of academic research and the closer firms are to universities (Mansfield 1995). Anecdotal evidence suggests highly innovative and performing entrepreneurial clusters are located in the vicinity of research universities, such as Silicon Valley around Stanford and the technology cluster around the University of Cambridge (known as the Cambridge Phenomenon). The most obvious channel through which knowledge flows from universities and other research organizations involves scientific research published in academic journals. This research is produced locally but it is distributed globally, and it is in principle available for anyone to use, independent of their geographical location. Yet, empirical evidence points to a different pattern. Jaffe and colleagues show that patents tend to cite other patents produced by organizations (both universities and corporations) that are located nearby (Jaffe et al. 1993). Even more strikingly, Adams (2002) finds that knowledge flows from universities tend to be much more local in nature than spillovers from firms, highlighting the apparent paradox that institutions whose mandate is to produce public knowledge, such as universities, tend to benefit disproportionately local businesses. Adams goes on arguing that it is precisely because of the open nature of the knowledge that is produced by universities, that we observe firms gravitating around academic institutions: as knowledge and information, especially if they are highly tacit in nature, do not transmit without costs, firms locate close to universities to absorb knowledge which is "reasonably current and not proprietary." Bergeaud et al. (2025) measure the scientific proximity of different industrial sectors to categories of academic research, and use this to identify firms that are 'close' to significant academic research in both scientific field and local geography (commuting zones). Firms that are nearby in this double sense spend more on R&D (both higher R&D wages and more R&D hours), patent more and are more likely to open new establishments. At the same time, recent contributions, such as Bikard and Marx (2020) challenge the importance of localized knowledge flows, by examining how geographic hubs, defined as "*a geographic concentration of patenting by firms in a specialized technical field*", connect academic science with corporate technology. This paper reconceptualizes how academic outputs become inputs to commercial innovation by demonstrating that hubs facilitate knowledge flow through both supply-side mechanisms (producing higher quality, more applied research) and demand-side factors (attracting disproportionate attention from firms). Most significantly, it reveals that hubs extend the geographic reach of academic knowledge by attracting attention from distant firms.

The important role of universities in fostering local/regional innovation and entrepreneurship makes support of universities an obvious component of policies designed to foster growth in particular regions through innovation. Gruber and Johnson (2019) discuss the problem of growing regional inequality in the U.S., and suggest a systematic effort to combat such inequality by funding regional innovation clusters. Examples of such policies include NSF's Regional Innovation Engines Program, the EDA's Regional Technology and Innovation Hub program, and programs in other countries such as Canada's Superclusters, the UK's Innovation Accelerators and the EU's Smart Specialization Strategies (Guzman et al. 2024).

Motivated by the establishment of major U.S. Federal programs seeking to harness the potential of regional innovation ecosystems, we assess the promise and challenges of place-based innovation policy interventions. Relative to traditional research grants, place-based innovation policy interventions are not directed toward a specific research project but rather aim to reshape interactions among researchers and other stakeholders within a given geographic location. The most recent such policy - the NSF "Engines" program - is designed to enhance the productivity and impact of the investments made within a given regional innovation ecosystem. The impact of such an intervention depends on whether, in its implementation, it induces change in the behavior of individuals and the ways in which knowledge is distributed and translated within that ecosystem. While this logic is straightforward, from it follows an important insight: innovation ecosystem interventions – Engines -- are more likely to succeed when they account for the current state of a given regional ecosystem (latent capacities, current bottlenecks, and economic and institutional constraints) and when they involve extended commitments by multiple stakeholders within that ecosystem. We synthesize the logic, key dependencies, and opportunities for real-time assessment and course correction for these place-based innovation policy interventions.

Guzman et al.'s emphasis that the success of such initiatives depends on the complex interactions among local firms and labor markets, local governments, and universities. The fuel of innovation-driven growth is research spillovers, and these spillovers manifest only if universities have the necessary capabilities and resources and are engaged with regional governments and firms. Policies of this kind can make a difference, but it is challenging because of the complexity of the local innovation system. Success depends on effective stakeholder engagement, holistic innovation system assessment, and implementable strategic choices. The dependence of local regional benefits on the local innovation system is highlighted by the challenges Europe has faced in capturing economic benefit from its investments in basic research. Nagar et al. (2024) undertake a comparison of the research outputs of projects funded by the European Research Commission (ERC) to the outputs of otherwise similar projects. They show that ERC-funded projects receive more patent citations than the control group, but the preponderance of these citations comes from patents of U.S. firms, both established and start-up. This shows that the magnitude of spillovers depends on not only on the 'spilling' organization, but also on the attention and capabilities of the potential recipients.

Discussion of regional innovation policy has focused on programs that seek to stimulate innovation in historically less innovative regions. But it should be acknowledged that the significant growth in university-led innovation and entrepreneurship in recent decades is itself part of the reason for growing regional inequality. Because proximity matters for spillovers, there is dynamic feedback whereby current innovation success fosters future innovation success. For the successful regions, this is a good thing, but at the same time it helps propel the successful regions farther ahead of the less innovative regions, exacerbating regional inequality. This means that generic innovation support policies, including public research funding and institutional/legal support for university technology transfer, work in the background to increase regional inequality. Further, many of these programs award public resources based on merit-based rankings; the successful regions attract the most talented researchers, who are the most successful in these competitive support mechanisms. So these competitive mechanisms act to give greater support to the regions that are already most successful. For maximizing overall innovation success, this is entirely appropriate, but it does mean that these programs are by design operating against the goal of reducing regional inequality.

3.3 Commercialization and entrepreneurship

The third mechanism through which universities affect innovation and growth is commercialization and entrepreneurship, the set of processes that transform academic discoveries into marketable products, services, and ventures. In operational terms, this includes invention disclosure, patenting, licensing, sponsored research with firms, and the creation and scaling of start-ups and spin-offs managed through technology licensing/transfer offices (TLOs/TTOs). Much of the contemporary literature on academic patenting and technology transfer has been shaped by two major policy shifts: the Bayh–Dole Act of 1980 in the United

States and the abolition of the professor’s privilege in several European countries during the late 1990s and early 2000s. The Bayh–Dole Act granted U.S. universities ownership of inventions arising from federally funded research, creating strong incentives for institutions to establish TTOs and actively manage intellectual property. This legislative change is widely credited with triggering a surge in university patenting and licensing activity, as well as the emergence of academic entrepreneurship as a distinct research field (Mowery and Ziedonis 2002; Grimaldi et al. 2011). Empirical studies following Bayh–Dole have examined the growth of invention disclosures, patents, licenses, and spin-offs, as well as the organizational and incentive structures that underpin these activities (Jensen and Thursby 2001; Thursby and Thursby 2002).

Proponents of the Bayh-Dole Act argue that industrial use of federally funded research would be reduced without university patent licensing. Our survey of U.S. universities supports this view, emphasizing the embryonic state of most technologies licensed and the need for inventor cooperation in commercialization. Thus, for most university inventions, there is a moral-hazard problem with inventor effort. For such inventions, development does not occur unless the inventor's income is tied to the licensee's output by payments such as royalties or equity. Sponsored research from the licensee cannot by itself solve this problem (Jensen and Thursby 2001; Thursby and Thursby 2002). The passage of Bayh-Dole was partly a reaction to rather than a cause of the emerging university technology transfer culture, but there is no question that the organizational and personal incentives created by Bayh-Dole reinforced and expanded that culture, and thereby played a major role in the growing entrepreneurial contribution of universities.

In Europe, the abolition of the professor’s privilege—a legal regime under which academic inventors retained IP rights—represented a parallel institutional experiment. Countries such as

Germany, Denmark, and Norway shifted ownership from individual researchers to universities, aiming to replicate the perceived success of the U.S. model. This policy change spurred a wave of research assessing its impact on patenting, licensing, and start-up formation. Evidence suggests mixed outcomes: while some universities professionalized their technology transfer operations, studies such as Hvide and Jones (2018) show that removing inventor ownership in Norway led to a sharp decline in both the quantity and quality of academic entrepreneurship and patenting.

A central and general empirical insight from the academic patenting literature is that university inventions are typically embryonic, "*little more than a proof of concept*", and thus require substantial inventor cooperation and downstream development by firms. In their survey of U.S. universities, Jensen & Thursby (2001) report that the most striking finding is precisely the embryonic state of licensed technologies and they argue that academic patents are best seen not as final outputs, but as intermediate inputs into firm R&D and commercialization. This also resonates with the observation that revenues from active commercialization or licensing of patents is usually very limited for universities, and that most TTOs/TLOs do not produce any profit but they are rather in deficit (Jensen et al. 2003).

Looking at academic entrepreneurship (university spin-offs and start-ups), literature has generally evaluated outcomes along several dimensions such as firm performance, economic impact, and implications for academic research. Empirical studies consistently show that university spin-offs tend to exhibit higher survival rates and innovation intensity compared to other start-ups, largely due to their strong scientific foundations and access to academic networks (Di Gregorio and Shane 2003). The results of this study provide insight into why some universities generate more new companies to exploit their intellectual property than do others.

We compare four different explanations for cross-institutional variation in new firm formation rates from university technology licensing offices (TLOs) over the 1994–1998 period—the availability of venture capital in the university area; the commercial orientation of university research and development; intellectual eminence; and university policies. The results show that intellectual eminence, and the policies of making equity investments in TLO start-ups and maintaining a low inventor's share of royalties increase new firm formation. The paper discusses the implications of these results for university and public policy (Di Gregorio and Shane 2003). However, their growth trajectories are often modest, with many remaining small and research-oriented rather than scaling into large firms. This may be due to the fact that academic technology spin-offs combine the traditional problems associated with starting a new business with the difficulties associated with the development of new technologies (Oakey et al. 1996). They therefore suffer from capital and credit rationing due to asymmetry of information, absence of venture capital markets, lack of collaterals and of complementary resources.

At the regional and national level, academic entrepreneurship contributes to knowledge-intensive employment and cluster development, but its aggregate economic impact is debated. Van Looy et al. (2011) argue that while individual universities' contributions may appear small, their cumulative effect across systems is "non-trivial" for competitiveness. Moreover, Grimaldi et al. (2011) stress that entrepreneurial outcomes depend on systemic factors, including venture capital availability, university policies, and researcher incentives. At the same time, an emerging literature has started to focus on the potential impact of universities on local entrepreneurship, business creation and overall economic activity.

Hausman (2022) uses the 1980 Bayh-Dole Act as a natural experiment to measure the causal impact of university technology transfer on surrounding regions. She develops a measure of university-industry technological proximity in regions, based on the frequency with which different industries patent in particular patent classes. This allows her to measure the closeness of the technological match between industry in a region and the university research in that region. She shows that after Bayh-Dole, better matched regions high higher employment and wage growth, and greater and higher quality (measured by citations) corporate patenting. Eesley et al. (2016) investigates how institutional reforms in universities influence entrepreneurial outcomes by analyzing China's Project 985, a policy aimed at fostering innovation in select universities. The authors find that the reform successfully shaped alumni entrepreneurs' beliefs about the importance of innovation and increased their engagement in technologically intensive activities, leading to a higher likelihood of founding high-tech ventures. However, these ventures did not achieve superior financial performance compared to those founded by entrepreneurs from non-985 universities or before the reform.

4. The Sectoral Context

Empirical work has often equated university spillovers with commercial outcomes, largely because they are easier to observe and measure. This approach has led to what appears to be a predominant focus on life sciences, where commercial outcomes are most visible- a classic case of looking for your keys under the lamp post because it is bright, rather than where they were actually lost. Yet understanding the differences in commercial outcomes across sectors, which we define broadly to include compositional differences across disciplines, patent technology fields, and economic sectors, is essential because the channels through which university research creates value, and the indicators that characterize those channels are not necessarily sector-neutral. What constitutes successful commercialization in biotechnology, where patents protect discrete molecular inventions and federal funding defines regulatory pathways, differs substantially from software sectors where copyright and trade secrets dominate, and development cycles are measured in months rather than years.

To bring these issues to light, this subsection presents results from a systematic analysis of articles on university commercialization to establish what is known about which disciplines, patent classes, and economic sectors are deemed important and/or statistically significant in making a commercial impact. By disaggregating what has typically been relegated to dummy variables or pooled analyses, we can identify where true sectoral heterogeneity exists and assess the extent to which findings from one sector apply to another. This analysis also enables us to synthesize the literature's various explanations on sectoral heterogeneity in moving towards a more unified understanding of how and why commercialization patterns differ across sectors.

4.1 The "Bio-ization" of Science: Is the Life Sciences Fundamentally Different? A Review of the Literature.

We perform a systematic review on university commercialization studies spanning four decades. From an initial sample of 47 studies, we retained 37 studies that both measure empirical effects of academic research and incorporate sectoral heterogeneity through academic disciplines, patent technology areas, or economic sectors. Using this filtered sample, we establish which sectoral contexts exhibit the greatest responsiveness to university research.[6] In doing this, we ask (a) how the literature classifies sectors—through academic disciplines, patent technology areas, or economic sectors, (b) whether they are single- or multi-sector studies, and which sectors appear more frequently, and (c) across these sectors, which yield what the authors deem to be significant commercialization effects. We classify commercialization effects as significant through two

[6] For the purposes of this conference, we provide preliminary results on 37 relevant articles that served as a basis for this chapter's literature review, which we can expand more systematically for future versions of this chapter.

approaches: studies testing for statistical significance through regression or other inferential methods, and studies using descriptive or correlational analyses that identify particular sectors as impactful based on magnitude or prevalence of outcomes.

Beyond these descriptive questions, this analysis addresses a long-standing question of life sciences' preeminence in university commercialization by testing whether their underlying disciplines, technology classes, and economic sectors receive a disproportionate amount of scholarly attention, whether they reflect a genuine importance in university research activity, or both. Either explanation raises questions about external validity and thus, is worth examining whether life sciences represent a unique case for absorbing and commercializing university research or whether their patterns generalize to the sectors such studies are often pooled with, a question we will return to following the presentation of results.

As a sub-chapter dedicated to heterogeneity, it is only fair to acknowledge the sheer heterogeneity of contexts in which this assessment of sectors sits. Some studies focus on the determinants of university research activity while others focus on the effects of that research activity. Nevertheless, we argue that research activity embodied in disciplinary, patent, and economic output possess inherent technological and market characteristics that persist despite variation within and across university research activity.

4.2 Findings

Table 1 presents the distribution of our systematic review sample across publication outlets and methodological approaches. The detailed list of articles analyzed and their results can be found in the Appendix. The sample spans economics, management, and policy journals distributed across four decades from 1985-2025.

Table 1: Breakdown of articles to journal and type of analysis

	Number of articles
American Economic Review	4
Journal of Urban Economics	2
Management Science	5
NBER Working Paper	5
Research Policy	13
Quarterly Journal of Economics	2
Regression	[to fill]
Descriptive	[to fill]

Note: The following journals contain 1 publication used in the analysis: American Economic Journal, Econometrica, Journal of Economic Geography, Review of Economics and Statistics, Science, and The Economic Journal.

Table 2 provides additional details regarding the use of different levels of aggregation of knowledge embodied in topic-based, invention-based, or economic-activity-based measures and outcomes. The majority of studies (n=31) employ pooled multi-sector analyses, though they vary considerably in how they handle sectoral heterogeneity. Some attempt additional sector-specific analyses typically relegated to footnotes or appendices, others make broader acknowledgments that heterogeneity exists among fields, while others use groupings of disciplines, patent classes, and sectors solely as control variables. While older studies tend to focus on one or two classification levels, more recent studies tend to incorporate all three- particularly by incorporating economic sectors into their analyses. Of the studies that perform single-sector analyses, which are too small in number (6 total) to derive conclusive evidence of a systematic focus on life sciences, all 5 nonetheless concentrate on this field, which itself falls within the life sciences category.

Table 2: Comparison across sector types under analysis and single- vs. multi-sector coverage

Article coverage across discipline, patents, and economic sectors	Number of articles
Discipline only	7
Patent only	3
Economic Sector only	5
Discipline-Patent	3
Discipline-Economic Sector	7
Patent-Economic Sector	1
Discipline-Patent-Economic Sector	10

Multi-sector analysis	31
Single-sector analysis (list)	6 (Biomedical; Neuroscience; Biomedical + Life sciences)
Significant findings in biomedical	30
Significant findings in non-biomedical	24, of which 22 use standard discipline, patent, or economic sector taxonomies

Note: If patents were included as a patent count with no reference to technology areas, they are not included in the count. Disciplines include studies that cover scientists, subject disciplines and university schools and departments. Note that biomedical also includes related sectors including biotechnology, chemicals/chemistry, drugs, and pharmaceuticals.

Among the 37 studies analyzed, 31 provided interpretations or results regarding sectoral heterogeneity. Of these, 30 reported that biomedical or life science sectors exhibited descriptively impactful and/or statistically significant commercialization effects, revealing a consistent pattern of biomedical exceptionalism across four decades of research. This empirical pattern definitively answers whether university research shows a statistically predominant effect in biomedical sectors- it does. Beginning with Jaffe (1989), who divides university departments into five technology areas across disciplines and patents, the positive effect of university research on local innovation is most concentrated in Drugs & Medical Technology followed by Chemical Technology with a significant but smaller effect. While Acs et al. (1992) extend Jaffe's patent analysis to include unpatented inventions from the U.S. Small Business Administration database, their results still confirm 'Drugs & Medical Technology' has the second highest invention yield per R&D unit input. Mansfield's (1991, 1998) economic sector analyses find the Drugs industry uses the highest proportion of academic research (27% products; 29% processes), with no other sector reaching even half this proportion except Instruments at 16% for products.

The pattern intensifies in post-Bayh-Dole studies examining the commercialization mechanisms that emerged after 1980. Jensen and Thursby (2001) show 44% of invention disclosures come from Medicine and nursing compared to 25% from Engineering and 19% from Sciences. Mowery and Ziedonis (2002) find biomedical patents consistently highly cited, regardless of university type, suggesting established quality advantages in life sciences commercialization. Cohen et al. (2002) report pharmaceutical firms' unique dependence on public research with 58% using it for new projects and 73.5% rating publications as important- far exceeding other sectors. This dominance persists through recent work: Belenzon and Schankerman (2013), extend Jaffe's early work on geographical proximity while incorporating more explicit state border effects to find that patent groups in Biotechnology, Chemicals, Pharmaceuticals, and Medical Equipment are all highly significant, with Engineering weakly significant, and Electronics, Information Technology, and Telecommunications not significant. (Lerner et al., 2025) focus exclusively on biomedical researchers when examining commercialization patterns across "academic movers" using the justification that biomedical research dominates commercialization outcomes.

While biomedical predominance is empirically established and will be discussed further in the following section, it is equally important to document significant commercialization effects in sectors outside of pharmaceuticals, chemicals, drugs, and biotechnology. 22 out of the 31 studies produce significant results outside of the life sciences, which stem typically from engineering disciplines and electronics-related sectors.

Table 3: Articles analyzed with non-biomedical significant results[7]

Article	Other Sectors of Significance
Jaffe (1989)	Electronics/Optics/Nuclear Tech
Mansfield (1991)	Instruments; Metals
Acs et al. (1992)	Electronics; Mechanical Arts
Rosenberg and Nelson (1994)	Agriculture and forestry; Electronics
Mansfield (1998)	Information processing, Instruments
Jensen and Thursby (2001)	Engineering, Sciences
Mowery et al. (2002)	Non-bio-medical patents

[7] Note that future versions of this table and analysis will disaggregate significance to its respective level of disaggregation (i.e., discipline; patent; economic sector)

Adams (2002)	computing
Thursby and Thursby (2002)	Disciplines: Material science, Computer science Patent: Physics Economic sectors: Semiconductors, Aerospace
Di Gregorio and Shane (2003)	Machinery
Audretsch and Lehmann (2005)	Hardware/technology
Audretsch et al. (2005)	Media
Woodward et al. (2006)	electronic & other electrical equipment, transportation equipment, instruments and related products
Abramovsky et al. (2007)	Machinery, electrical machinery, tv & radio equipment
Belenzon and Schankerman (2013)	engineering
Cowan and Zinovyeva (2013)	Veterinary and agriculture
Scandura (2016)	Manufacturing of motor vehicles, medical products, and metal products
Ahmadpoor and Jones (2017)	Patents: superconducting technology, artificial intelligence Disciplines: computer science hardware and architecture
Babina et al. (2020)	engineering
Marx and Hsu (2022)	Engineering, electrical and electronic
Arora et al. (2023)	Electronics/semiconductors, Machinery, equipment, systems
Babina et al. (2023)	engineering
Bergeaud et al. (2024)	Aircraft machinery, engineering studies, electronic components, communication equipment, plastics
Rezaei and Yao (2024)	Computer Science, Engineering, Physics

4.3 Discussion

The systematic patterns revealed in our analysis raise questions about why certain sectors consistently demonstrate stronger commercialization effects from university research. While the literature offers various explanations for sectoral heterogeneity, these discussions inevitably center on biomedical fields as the exemplar case, both because they dominate empirical studies and because they exhibit the clearest commercialization patterns. Thus, any attempt to theorize sectoral differences must grapple with why pharmaceuticals and biotechnology so consistently outperform other domains in translating academic research into commercial outcomes. Notwithstanding, it is worth noting that most secondary yet significant sectoral effects do arise from engineering- and electronics-related sectors to be discussed in detail below. While most effects do not remain statistically significant when measured through patents and technology fields, descriptive and survey-based approaches analyzing these economic sectors provide a secondary story of commercialization.

4.3.1 Explanations from the Literature

Ahmadpoor and Jones (2017) mention three factors that provide an explanation for sectoral heterogeneity: the nature of the research, institutional factors, and temporal distance in terms of development cycles. These factors align well with how the studies in our analysis interpret their own heterogeneous findings. We synthesize these explanations below, first examining what the literature reveals about life sciences, followed by an analysis of electronics and engineering which are the second and third most frequently listed significant sectors, but will be analyzed together given the significant overlap of both in the studies' explanations. We then offer considerations for how future research might better capture commercialization patterns in underexamined and mismeasured sectors.

Life Sciences

The first and most basic explanation centers on the inherent nature of knowledge across sectors. Multiple studies converge on the idea that biomedical fields possess inherent characteristics conducive to observable commercialization. Life sciences knowledge is highly codified through established scientific protocols and publications, with biology providing the core basis for pharmaceutical innovation. Welsh et al. (2008) describe university biological research as "basic and embryonic," while Thursby and Thursby (2002) note biology is "particularly important for pharmaceuticals" due to the biomedical nature of drug discovery. This translates into distinctive innovation processes, as life sciences shows the "tightest linkage between research and innovation" compared to other fields relying on "incremental engineering advances" (Jaffe 1989), with molecular biology positioned closest to the paper-patent boundary (Ahmadpoor & Jones 2017). This dependency on academic research is not merely theoretical but manifests in concrete outcomes, as demonstrated in Mansfield's series of firm survey showing that firms rely the most heavily on products and processes in Drugs. This creates a distinctive complementarity pattern where, unlike other sectors showing crowding-out effects, life sciences is the only domain where public knowledge and internal corporate R&D function as strategic complements (Arora et al. 2023).

Regarding the role of institutions and resource concentration, the biomedical advantage reflects decades of investment and visible measures of inventive activity. Welsh et al. (2008) posit that the university was the birthplace of the biotechnology industry. Mowery et al. (2002) attribute the consistent high quality of university biomedical patents relative to other technology fields to the long history of biomedical funding and subsequent research (particularly from the NIH) that enabled universities to build strong biomedical capabilities before Bayh-Dole, while non-biomedical fields required "institutional learning" post-1980. This can also be reflected in what Jensen and Thursby (2001) identify with 'Medicine and nursing' having the highest share of university invention disclosure at 44% of the total. More recent literature confirms this ongoing trend, with the highest university patent shares found in genetic engineering (18.1%) and molecular biology (12.1) (Babina et al. 2020).

The temporal dynamics of biomedical commercialization create unique path dependencies that reinforce sectoral advantages. While Ahmadpoor and Jones (2017) find that molecular biology sits closest to the paper-patent boundary, suggesting tight research-application coupling, the extended development timelines in pharmaceuticals, often spanning decades from discovery to market, create sustained university-industry relationships that differ from sectors with rapid product cycles. This temporal structure generates self-reinforcing patterns. Pharmaceutical firms' unique dependence on public research (58% for new projects according to Cohen et al. 2002) creates sustained demand-side pull, while funding concentrates in fields already demonstrating commercial promise, with "Big Science" grants being four times more likely (Rezaei and Yao 2025). The cumulative effect of these temporal dynamics is so pronounced that Bergeaud et al. (2025) explicitly remove chemistry/pharma from robustness checks to ensure results aren't driven by these "most affected units," recognizing their outlier status in university spillover sensitivity.

Non-Life Sciences

Nelson and Rosenberg (1994) noted that "the lion's share of university research is in the engineering disciplines and applied sciences…which, by their nature are oriented towards problem-solving" rather than basic discovery. This problem-solving orientation persists today, yet paradoxically, these sectors show weaker commercialization effects than biomedicine despite their natural alignment.

Upon closer examination, our analysis attributes much of this decreased magnitude to the use of patents as a measure of inventive activity. Rather than attempting to identify significant sectors through patent subsets alone, it is as important in these fields to look at representative subsets of firms across a diverse range of economic sectors. The importance of non-biomedical sectors becomes more visible when measuring firm sentiment and alternative indicators particularly relating to firm reliance on university research. Mansfield's family of firm survey literature (1991, 1995, 1998) show that firms classified into 'Instruments' consistently rely on academic research, ranking second to ‘Drugs.’ Arora et al. (2023) investigate the mechanisms behind university dependence, finding that Electronics firms benefit more from hiring PhD graduates than from use of publications or patents. They also find that while Machinery/Equipment firms benefit from PhD graduates, these firms view university patents in related fields as competitive rather than complementary to their own capabilities.

The studies that identify significance in engineering at the patent level include Jaffe (1998) and Babina et al (2020), where Jaffe finds weak, yet statistically significant positive effects of geographic proximity between universities and firms, while Babina finds that an increase in federal funding not only decreases patenting in bio/med/pharma, but also in engineering as well as the basic sciences. Rezaei and Yao (2024) find that neuroscience startups are 2.5 times more likely to file specifically AI patents upon participating in a wider neuroscience initiative. While they also find disciplinary significance in Engineering, Computer Science, and Physics, representing a wider range of disciplines, 88% of the startups in what the authors define narrowly as the “neurotechnology sector” belong in the broader healthcare sector, with 8% also in IT. This demonstrates the multi-disciplinary nature of certain high-tech technologies, as well as the multi-purpose of AI-related patents as well.

The studies that identify significance in engineering at the patent level include Jaffe (1998) and Babina et al. (2020). Jaffe finds weak but statistically significant positive effects of geographic proximity between universities and firms, while Babina finds that increased federal funding decreases patenting not only in bio/med/pharma, but also in engineering and the basic sciences. More recently, Rezaei and Yao (2024) demonstrate how interdisciplinary research can blur traditional sectoral boundaries: neuroscience startups participating in the BRAIN Initiative became 2.5 times more likely to file AI patents. While the Initiative showed disciplinary significance across Engineering, Computer Science, and Physics, 88% of "neurotechnology" firms remained classified in the broader healthcare sector, with only 8% in IT. This illustrates how emerging technologies increasingly span multiple disciplines, with AI-related patents serving as bridges between traditionally distinct sectors.

4.3.2 Additional Considerations

Taking a step back from this literature review reveals what the findings tell us through their silence as much as their presence: the literature's preeminence of life sciences is partly genuine but more likely partly an artifact of how we measure and conceptualize commercialization.

The absence of consistent robust findings in engineering (with the exceptions noted above), software, and service sectors (with the exception of Media noted above), which collectively employ more researchers and generate more economic activity than biomedicine, suggests not that these fields lack commercial impact but that our measurement frameworks fail to capture it. When impact is proxied by patents, licenses, and royalties, the life sciences dominate by construction as they more cleanly map onto discrete pharmaceutical products, providing clearer evidence of commercialization than the fragmented value chains found in electronics and engineering, or the data asset heavy basis of computer science.

Together, these factors ensure that most empirical studies, and by extension most policy lessons, derive from biomedicine. Yet relying on one sector whose products enjoy the strongest appropriability conditions, codified regulatory pathways, and generous public subsidies raises fundamental questions about external validity, a consideration crucial when interpreting the effects of university research activity across more than one sector. While the literature documents substantial industry responses to academic research in pharmaceuticals, including strong geographic proximity premiums, assuming these patterns generalize to sectors with weaker appropriability, shorter product cycles, and cumulative rather than discrete innovation represents a leap of faith unsupported by current evidence. This recognition demands examining two critical issues: how measurement choices systematically shape our understanding of commercialization, and how sector-specific mechanisms determine which pathways prove viable for translating academic research into economic value.

Measurement Challenges

The long-recognized measurement challenges in academic commercialization stem from the question of where value creation occurs, and the choice of which level of aggregation to measure it at. Does it reside in the codified knowledge of publications, in invention disclosures, or embodied in economic sectors? Two methodological considerations have become increasingly critical as the literature employs more sophisticated microdata, linkages, and crosswalks. First, the choice of the unit of analysis captures different phenomena and levels of research activity. Studies based on academic disciplines measure knowledge production at the institutional and researcher level, patent classes group technologies by technical similarity regardless of market application, and economic sectors reflect market endpoints regardless of technological origin. The choice of the unit of analysis is important and should be justified to ensure alignment between the measurement approach and the underlying economic phenomenon of interest.

Second, when our units of analysis are mapped to a broader classification, and that classification is combined with others into a concordance, such research design choices affect not just technical details on research activity, but broader phenomenological-based conclusions about which sectors benefit from academic research, which universities excel at commercialization, and which policies effectively enable technology transfer. These choices introduce distortions that range from indicator mismatches that overstate effects in patent-centric fields while attenuating them elsewhere, misclassification errors from imprecise concordances that change over time, and aggregation bias that conflates general-purpose technologies with narrow applications. With NAICS codes characterizing markets structures, IPC classes representing patent-intensive technological development, and academic disciplines representing knowledge production norms, we make implicit assumptions that may characterize commercialization in pharmaceuticals, but fail when attempting to interpret findings on “non-biomedical” aggregates. While we make no attempt to provide a uniform solution to this decades long issue, we acknowledge more recent advances by Bikard and Marx (2020), Rezaei and Yao (2025), and Bergeaud et al. (2025) that use Natural Language Processing to more cleanly map research activities into commercialization channels.

Sectoral Bias

Shifting from measurement and value creation to value capture requires examining how inherent sectoral characteristics shape commercialization patterns. Three key components underlying commercialization processes, the technology type (i.e., the nature of the knowledge), the market structure (i.e., the regulatory and competitive environment), and the appropriability regime (i.e., the mode of value capture), are often examined separately in the literature, yet taken together, characterize the array of permutations that make up disciplinary-, technological-, and sectoral-distinct commercialization channels. For example, pharmaceuticals often feature discrete molecular inventions with strong patent protection in concentrated, highly regulated markets, favoring exclusive licensing and university spin-offs. Contrastingly, software's cumulative innovation, weak patents, but strong network effects and low entry barriers drive commercialization through human capital flows and open-source contributions.These patterns suggest that effective knowledge transfer depends less on the transfer mechanism itself than on alignment between the mechanism and underlying sectoral characteristics.

What implications does this have for the nature of what types of academic research get commercialized, by whom, and how? Starting with appropriability regimes, early work by Arrow (1962) and Mansfield (1991, 1995) posits that IP strength varies dramatically across sectors with pharma showing substantial dependence on university research compared with 1% in petroleum, patterns that also persist when examining university licensing activity. This variation in appropriability highlights which transfer mechanisms to adopt: sectors with strong IP protection favor formal channels that range from defensive patent portfolios to exclusive licensing, while weak appropriability introduces commercialization through tacit channels (e.g., human capital flows, collaborative research, and informal networks). The strategic use of IP also differs, where the life sciences build defensive patent thickets around core inventions while software companies use patents offensively for cross-licensing negotiations rather than exclusion. These appropriability-driven differences interact with organizational incentives, where universities prioritize broad knowledge dissemination and faculty freedom to publish, while firms focus on competitive advantage and controlled disclosure timing, creating inherent tensions over the pace, scope, and exclusivity of technology transfer activities. There is more discussion on such tensions in the Culture & Mission section of this chapter.

Market structure also shapes channel selection through regulatory timing and competitive dynamics, though this component receives less systematic attention in the academic commercialization literature and resides more naturally in industrial organization. A separate challenge lies in the often indirect, harder to detect influence in the organization of firms and markets for technology given the literature's emphasis on disciplinary- and patent-level academic output. Thus, isolating the impact of market structure on university commercialization success and vice versa proves difficult, as commercialization inherently involves matching uncertain supply from universities to volatile market demand, where entrepreneurs and products frequently fail along complex pathways from lab to market. Nevertheless, regulatory interventions provide some insight into how market structure matters. The Bayh-Dole Act's differential impact across sectors illustrates this precisely, succeeding in pharmaceuticals where it aligned to existing market structures while proving less transformative in sectors with shorter product lifecycles and lower barriers to entry. Similarly, (Azoulay, n.d.) demonstrates how federal funding agencies' timing requirements interact with sector-specific channels of commercialization. For example, NIH grant cycles align with FDA approval timelines compared with NSF engineering grants that cannot replicate the same coordination.

These market structure considerations extend beyond life sciences to broader questions of the timing and lags involved in commercialization. While Mansfield found an average of 7 years from academic research to industrial application, these timelines vary dramatically by sector that range from real-time iterations in software to decades in material sciences, which have also likely shifted over the past three decades as digital technologies and automation shorten some development cycles while regulatory milestones are extended in others. Such temporal heterogeneity shapes university-industry engagement and characteristics of success within academic entrepreneurship. Thus, this variation in timing and market dynamics calls into question broad-stroke policy interventions that assume uniform commercialization pathways across sectors, particularly when sector-specific interventions are used to infer effects across multiple, structurally different industries.

The third component, technology type, which encompasses the nature of knowledge itself (distinct from the units of analysis discussed earlier) is often most closely situated to the university and examined in the literature. Three characteristics of knowledge emerge as factors shaping commercialization mechanisms. First, the discrete versus cumulative nature of innovation which has been shown to influence external engagement modes of universities (Perkmann et al. 2011), and with universities (Cohen et al. 2002). Second, knowledge codifiability impacts the transfer mechanism adopted, with highly codified knowledge transferring through patents and publications, whereas tacit knowledge particularly in engineering and manufacturing sectors requires more informal exchanges, proximity, and collaboration. Third is the distinction between general-purpose technologies versus narrow applications. These characteristics systematically vary across sectors, with software emphasizing human capital flows and open-source contributions versus biotechnology relying on formal patent licensing and exclusive agreements. This alignment between knowledge characteristics and transfer mechanisms suggests why some succeed and others fail.

Takeaways

What to take from this? These measurement and aggregation challenges point towards a necessary evolution in both research design and policy formulation. Future work should develop sector-appropriate indicators that capture value creation in the data-driven economy, where pre-trained models, algorithms, and datasets represent primary outputs, and it should account for increasingly globalized, complex, multi-sector supply chains where university contributions may be several steps removed from final products. For policy, the imperative is clear. Copy mechanisms, not sectors. Attempting to replicate biomedical commercialization models in fields with different knowledge characteristics, market structures, and appropriability regimes wastes resources and impede knowledge transfer. Effective commercialization policy requires sector-specific interventions that address the particular market failures and transfer mechanisms dominant in each domain.

5. Artificial intelligence

Chapter XX[8] discusses overall the contributions of AI to science, but a brief comment is in order here on the unique position of AI within the overall contribution of universities to innovation and growth. While we don't yet know what the long-term consequences of AI will be, it is already clear that tools such as machine learning, neural networks, natural language processing and large-language models are already making major contributions to innovation across a variety of fields, including software engineering, autonomous devices and vehicles, drug development, precision agriculture, personalized health care, etc.

General Purpose Technologies ("GPTs") are an important source of knowledge spillovers, because their applicability to a wide variety of sectors generates a positive feedback loop in which they are used in many different ways in different places, and those uses generate improvements in the GPT which can then be shared across the many different applications. AI tools are a kind of general-purpose *innovation* technology, which are being used to develop new applications in a wide variety of different settings. These many different uses in turn then generate improvement in the tools and to some extent these improvements are shared, generating potentially enormous innovation benefits and social returns.

[8] Chapter number to be added once book chapter numbers are allocated; reference to The Economics of AI and Science' chapter

While we do not think of AI today as coming from universities, we would not be where we are were in not for a very long gestation period of research that was largely an academic undertaking. In the coming decades we may come to see the long-run social benefits of this academic research as being comparable to those of the biotechnology revolution.

In the medium term, much of the cutting-edge AI work is now centered in firms; numerous academic AI researchers are either dividing their time between academia and industry, or else moving entirely to industry. Interestingly, while the monetary rewards of commercial AI work have no doubt played a role in this shift, there is also evidence that the dependence of AI research on computing resources and very large datasets makes the commercial setting more attractive apart from the personal financial rewards. Yu (2024) examines the research output of researchers with both academic and industrial affiliations, and finds that their corporate-affiliated work is significantly more impactful as measured by citations, and shows that this higher quality can be attributed to the greater resources available to the corporate research. Thus, while biomedical research dominated and shaped our perceptions of the commercial benefits of university research in previous decades, we may in the coming decades experience a changed and perhaps diminished impact if AI the importance of AI continues to grow.

6. Countries

Just as sectoral characteristics shape the pathways through which academic research generates commercial impact, the country context also influences both the scale and mechanisms of university commercialization. The variation is evident when comparing different forms of research output: for 2022, U.S. universities performed $91.4 billion in R&D and represent 10% of total national R&D, while European institutions in the EU-27 collectively performed research worth $474.1 billion but with higher education accounting for 22% of total national R&D. UK universities maintain substantial industry research partnerships despite generating proportionally more research output per capita than their American counterparts, yet with different commercialization pathways.

The funding structure reveals differences in how nations organize research. The broadly decentralized American system still relies heavily on federal funding, with government sources providing 53% of university R&D funding through agencies like NIH ($34.0 billion in life sciences) and NSF ($7.4 billion across disciplines). This contrasts with European models where Germany and France see government funding reach 30% of total national R&D compared to 20% in the United States, and where regional R&D intensity plays a more significant role in university-industry collaboration patterns. Chinese investment in higher education R&D represents an entirely different scale of centralized commitment to academic research infrastructure.

The nature of industry collaboration varies across these systems as well: while only 6% of U.S. university research receives direct industry funding ($5.5 billion in 2022), European research papers suggest stronger regional integration where contract research relationships are more faculty-distributed and spin-off activities benefit from dedicated technology transfer office support.[9] The policy emphasis using nearly equivalent mechanisms yield highly different outcomes: the United States' Bayh-Dole Act of 1980 has often been viewed as a gold standard for university technology transfer, yet its replication across most of the developed world has produced far more nuanced results.

[9] Statistics drawn from U.S. 2024 NSB

These divergent approaches reflect how different nations develop distinct strategies shaped by their unique institutional histories, legal frameworks, and cultural contexts (Grimaldi et al 2011; Guena and Rossi, 2011). Such nuances prove critical when considering the external validity of commercialization models developed in the U.S. context versus their applicability to European, Asian, and other global contexts. Understanding these relationships requires examining both supply-side factors, as well as often the more fuzzy, yet equally critical demand-side characteristics that help translate R&D into commercial output.

6.1 Some Facts: Cross-Country Patterns in University Commercialization

The question of identifying country-specific characteristics that characterize the organization and production of its underlying research is important and already a daunting task that often involves identifying a natural experiment and isolating the many factors influencing academic research into one that can identify how and why research operates the way it does. Taking such findings and then extrapolating them to other country contexts becomes a comparison between national systems that implicitly, yet often falsely, assumes similar contexts, industry compositions, levels of development, and a prioritization of the same technology transfer channels, all of which give rise to a question of external validity. What doesn't help is the limited country coverage of the literature, which traditionally characterized academic engagement and commercialization from the context of the United States and Europe, at times extends to other OECD countries, and more recently has begun to increase for China, South Korea, and Japan.

Given the state of this limited coverage, which also provides ample room for future research, it is worth first presenting some stylized facts on a more globally representative selection of countries before outlining the Western-heavy findings comparing the United States to Europe, and often with an emphasis on Bayh-Dole and Bayh-Dole-like policies as a natural experiment which is important, yet decades old. This comparative analysis necessarily relies on traditional commercialization metrics (i.e., publications; patents; licensing) that, as discussed elsewhere in this chapter, tend to overemphasize certain mechanisms while underrepresenting others. Despite these measurement limitations, these indicators remain the most feasible basis for systematic cross-country comparisons and represent channels with demonstrated economic significance in translating academic research into commercial applications.

6.1.1 Knowledge Production and Academic Engagement

Presented below are some statistics on the knowledge production side of university research, which will then be followed by statistics on direct commercialization activities. We distinguish between the production of research and the exploitation of research as two fundamentally differing sets of activities undertaken by universities and are often influenced by the country context. Why? Firstly, based on the accounts of the European Union that coined the "European Paradox"- [one that European countries produce similar levels of academic output quality, but perform poorly in commercialization]. And secondly, Perkmann et al's (2013) distinction between academic engagement and commercialization where they posit that the exploitation of academic research operates as a follow-on activity, and quite differently in terms of faculty versus institutional roles. This gives reason to believe that the various permutations of these decisions are both affected by, and affect country-level academic research activity.

[placeholder for own analysis to be added in a later version of this draft]

6.1.2 Formal Commercialization Mechanisms

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6.2 Explaining Cross-Country Variation

It is worth turning to the literature to provide reasoning for the variation in research activity and output by country, particularly as these differences persist despite decades of policy and development convergence. The following subsection will examine two supply-side factors, IP ownership regimes and funding mechanisms, that dominate the literature and discuss how their interactions with national demand-side factors jointly shape academic research activity and contribute to distinctive national commercialization profiles

6.2.1 Supply-Side Determinants

The choice of how academics research, on what, and in what form of output reflects decades of institutional updates influenced by historical academic orientation, legal frameworks governing intellectual property, and funding structures that incentivize different forms of research. Rosenberg and Nelson (1994) recount how American universities developed "practical" orientations through land-grant institutions, while Di Gregorio and Shane (2003) document how its startup culture only amplified post-Bayh-Dole at institutions with established industry ties. Yet several questions emerge from cross-national comparisons, as shown in the illustrations above: What explains persistent variation in commercialization outcomes despite policy convergence? How do institutional contexts mediate the effectiveness of similar policy frameworks? And why do countries with comparable R&D investments produce different patterns of knowledge transfer? The literature reveals a number of characteristics that give way to heterogeneous outcomes and practices across countries, but two factors consistently emerge: one of IP ownership, and one of funding structures and government support.

Intellectual Property Ownership and the European Historical Narrative

The majority of literature examining academic commercialization in countries outside the United States focuses predominantly on intellectual property ownership regimes in Europe. This concentration likely reflects both the importance of IP ownership in shaping university research activity and its outcomes, as well as its visibility as a natural experiment in providing a robust empirical testbed. The abolition of "professor's privilege" across multiple European countries in the early 2000s created particularly compelling quasi-experimental conditions for studying policy effects, and while we will lay out the key findings of this literature here, it is essential to emphasize that much of the magnitude and impact derived from these IP ownership updates depends critically on the pre-existing institutional conditions in the countries under analysis.

The contrasting evolution of European higher education compared with the United States, and even within Europe itself reveals how institutional conditions impact research orientation and commercialization patterns, differences that remain visible centuries later. Unlike American land-grant universities dedicated to using science as a service to society from their inception, European institutions followed trajectories rooted in aristocratic traditions with a theoretical emphasis that created lasting structural divisions. German research universities like Heidelberg and Berlin pioneered laboratory-based science under the Humboldtian model, which emphasized pure research and academic freedom but remained oriented toward advancing knowledge rather than meeting immediate industrial needs. In Britain, Oxford and Cambridge held onto classical curricula well into the late 19th century, while technical education developed in separate institutions such as the Royal College of Science and later the red-brick universities.

This European pattern maintained a sharper divide between elite research universities and vocational training until well into the 20th century, with applied science largely confined to polytechnics like ETH Zurich and Technische Hochschule in Munich, which only later gained university status. Most tellingly, until the late 20th century, European universities prohibited or discouraged patenting, leaving intellectual property to individual professors under "professor's privilege" systems while channeling technology transfer through separate state research institutes like Germany's Fraunhofer Society and France's CNRS rather than through universities themselves. These institutional arrangements, established centuries earlier, help explain why European adoption of university IP ownership lagged the United States by nearly two decades and why similar policy frameworks continue to produce divergent commercialization outcomes across different national contexts.

Against this backdrop, the literature highlights the within-European patchwork of university IP ownership that emerged as countries grappled with balancing traditional academic norms against pressures for greater commercialization. The coexistence of professor's privilege and institutional ownership models created misaligned incentive structures across much of the continent.

Geuna and Rossi (2011) divide these countries into five groups based on their underlying transitions in university IP ownership which include those maintaining professor's privilege over time (Sweden and Finland), earlier adopters of institutional ownership (the UK since 1977), recent converters to institutional ownership (Germany in 2002 and Norway in 2003), countries that unusually moved from institutional ownership back to professor’s privilege (Italy in 2001), and former Eastern European countries that transitioned from government to institutional ownership. Their analysis reveals that these policy changes produced markedly heterogeneous outcomes, with the effectiveness of reforms depending heavily on pre-existing academic cultures, institutional capacity for technology transfer, and the broader innovation ecosystem surrounding universities.

Hvide and Jones (2018) provide the most compelling causal evidence from Norway's 2003 abolition of professor's privilege, estimating a 50% decrease in patenting and startup formation rates, an outcome directly inverse to what Bayh-Dole achieved in the United States, where institutional ownership increased university patenting substantially. This stark result aligns with broader patterns identified by Perkmann et al. (2013), in showing that professor's privilege correlates with higher rates of individual academic consulting and informal knowledge transfer, while institutional ownership increases formal licensing but reduces entrepreneurial activity. Together, these findings underscore how identical policy frameworks can produce contradictory results when implemented in different institutional contexts.

Cross-Country Funding Arrangements

National R&D funding structures reveal distinct approaches to academic research, commercialization incentives, and industry engagement. These varying compositions of funding sources, from mission-oriented agencies to excellence-based grants, create different opportunities and pressures that shape both research priorities and commercialization outcomes. For example, the United States exemplifies mission-oriented funding through agencies like NIH and DoD, which embed practical relevance requirements even within basic research programs. Sampat (2006) documents how 68% of university research was federally funded by 1980, though this share has declined to approximately 52% by 2022 as private industry support has grown more rapidly.

This contrasts with European approaches where the European Research Council explicitly avoids commercial criteria in favor of "frontier research," yet Nagar et al. (2024) find it paradoxically generates 11.79 EPO patents per €10 million versus 5.72 USPTO patents, suggesting that excellence-based selection inadvertently identifies commercially relevant research. Other recent evidence from Bergeaud et al. (2025) reinforces these systematic differences, comparing French funding through direct Laboratories of Excellence (LabEx) grants versus R&D tax credit systems and finding that the targeted competitive program generated 3.4 times more patents per euro than broad tax incentives. National R&D tax credit designs create additional variation in university-industry engagement patterns. Koch and Simler (2020) show that the U.S. credit at 20% primarily benefits large firms with sustained R&D programs, the UK's 230% SME deduction increases university interaction with smaller firms, while France's Crédit d'Impôt Recherche allows university contracts to qualify as expenses at 30% up to €100 million, directly subsidizing academic collaboration. These design differences demonstrate how funding mechanisms not only determine which types of firms and research projects receive priority within national innovation systems, but also fundamentally alter the structure and intensity of university-industry relationships.

Other Considerations

Beyond funding and IP regimes, other factors outlined both in and outside of the literature include academic mobility constraints, with Audrestch et al. (2005) documenting that academics in Germany are largely immobile. Proximity to industry and local development needs remains a central concern (Cowan & Zinovyeva, 2013). Outside of the sphere of academia, inherent characteristics such as language asymmetries that serve as an advantage to anglophone researchers in global markets, and cultural attitudes towards risk taking and entrepreneurship also important conditions outside of immediate policy control.

6.2.2 Demand-Side Considerations

The exploitation of academic knowledge represents a critical yet elusive component of the commercialization equation. While supply-side factors determine what knowledge universities produce, demand-side characteristics dictate whether and how that knowledge generates commercial value- a distinction particularly crucial for smaller countries that cannot rely on scale alone. Van Looy et al. (2011) posit during their analysis of 105 European universities that "although the small numbers implied at the level of any individual university would mean that such actions contribute only marginally to the competitiveness of the European knowledge economy, the sheer number of European universities as well as the potential cumulative effect of their efforts might result in a non-trivial contribution." This observation suggests that particularly from a small open economy, non-U.S. context, the whole is greater than the sum of its parts, and economies of scale and scope significantly influence commercialization outcomes.

But what prevents countries from capturing these system-wide benefits? Is it a lack of industrial capacity, or something more fundamental about how firms and universities interact? Two key factors emerge from the literature. Firstly, knowledge sourcing and external alliance patterns shape how firms access and value university research. And secondly, the state of markets for technology either enables or constrains the commercial application of academic inventions.

As outlined earlier in this chapter, firms make use of universities through multiple channels: collaborative research projects, contract research, consulting arrangements, licensing agreements personnel exchanges, and other forms of informal knowledge transfer through publications and conferences. Yet how firms engage with universities and use academic knowledge varies dramatically across national contexts. Mansfield (1995) and Cohen et al.'s Carnegie Mellon Survey reveal that U.S. firms primarily value universities for fundamental research that informs

R&D direction rather than immediate collaborative projects. This pattern of limited formal engagement becomes even more pronounced outside of the United States.

Bercovitz and Feldman's (2006) analysis of Canadian firms reveals sparse interaction patterns, with companies reluctant to engage directly with universities with the exception of narrowly defined projects that complement existing internal R&D capabilities. The European context presents an even starker contrast, with Lauren and Salter (2004) finding that UK and EU manufacturing firms overwhelmingly rely on within-enterprise sources for innovation, with only 2% rating universities as "highly important" for their inventive activities.

These cross-national disparities persist when examining formal commercialization mechanisms like licensing. U.S. universities generate substantially higher licensing revenues per research dollar than their European counterparts, a difference that reflects not superior technology but different industrial structures. Firm size also plays a role, with smaller firms lacking extensive internal R&D capabilities, so they actively seek external technologies and show greater willingness to license university inventions. All in all, this reality underscores a limitation in university commercialization strategies given there is only so much relevant research output and industry outreach that can take place, when successful commercialization ultimately hinges on firms' willingness to exploit academic knowledge. Beyond willingness, there remains an even more fundamental question of whether the industrial context is sufficiently mature and populated with firms possessing the absorptive capacity to recognize and translate academic knowledge into a commercial application.

While such demand-side constraints can be partially mitigated through direct academic entrepreneurship, academic entrepreneurs face inherent structural barriers to market scale and fragmentation. Consider the scaling challenges: a U.S. academic entrepreneur can target a unified market of 330 million consumers with a common language and regulation, while a French entrepreneur faces a domestic market of 67 million, necessitation the navigation of the broader European Union's 450 million consumers across 27 different regulatory regimes and languages. South Korean academic entrepreneurs, despite strong technological capabilities confront a domestic market of 52 million, forcing immediate internationalization strategies that require resources and expertise typically found beyond academic founding teams. What might succeed as a viable enterprise in the large, homogenous U.S. market may be structurally unviable in smaller or more fragmented markets, regardless of the underlying technology's merit or the founding team's capabilities.[10]

6.3 Academic Commercialization and Development: What can be Learned?

To what extent can the rest of the world learn from high-income countries' experiences with academic commercialization? The evidence suggests no universal model exists for successful university commercialization, with outcomes depending on complex interactions between supply-side determinants, demand-side characteristics, and broader national characteristics. The United States has particularly benefited from favorable conditions across all dimensions; however, countries attempting to emulate its practices without considering this context will likely encounter disappointing results.

Let's begin with the more obvious takeaways. First, the balance of IP ownership between university inventors and the universities themselves matter. The international standard set by most developed countries is one of primarily university ownership. This raises the question of the inner workings of the university and what constitutes an appropriate incentive system for

[10] https://ncses.nsf.gov/pubs/nsb20243/key-takeaways

inventors, which is an important consideration regardless of the country context. A cross-country institutional comparison would yield interesting and important insights. But what remains severely understudied in the literature, or for the sake of this chapter- the set of journals that are informing it, is a question of what Perkmann et al's (2013) academic engagement and academic commercialization look like in cases where countries have weaker IP regimes, whether universities have TTO offices, or whether patents are even a viable form of IP protection and/or a source of revenue. This presents a fundamental question of how to measure inventive activity within such universities, trace out commercialization efforts, and identify mechanisms to incentivize research in certain fields. And as countries develop technological capacity, determining what incentives to build or modify within university systems to increase commercializable output becomes crucial, particularly regarding the appropriate balance between quantity and quality of research outcomes.

Second, successful research exploitation demands comprehensive funding ecosystems which can consist of different funding instruments as outlined in the literature. [funding can take form in tax breaks or subsidies, target universities and firms, etc.]. What remains understudied but appears to be a trend is the adoption among high-income countries towards institutional block funding—exemplified by the UK's Research Excellence Framework and Australia's analogous system, which provides greater stability and longer-term planning objectives for university researchers than project-based grants. This stability becomes particularly crucial for countries with centralized, government-supported university hierarchies. The United States' decentralized system of autonomous institutions represents an anomaly requiring careful consideration when assessing external validity.

But what we argue to be just as important, if not more than a national ecosystem of support, and what the literature more often than not hops over is the spillover. We return to the spillover, and with the literature focusing greatly on the appropriate ingredients for a university to support broader commercialization, and the sometimes necessary, sometimes unnecessary localization of firms, this embeds 2 key assumptions that require a double click in not just a developing country context, but a small open economy context: the assumption that there is some source of absorptive capacity within the same geographical borders as the idea or invention itself, and secondly, the assumption that there is a sufficiently sized market for technologies within the same geographical border as the idea or invention itself. While such assumptions often hold true in the United States, China, and Indias of the world, or as Van Looy (2011) points out- the cumulative effect the European Market has in inventive activity- what about the rest of world? What does this spillover look like? Is there interested and absorptive capacity right across the border, or must university inventors seek out destination markets even prior to considering how to spend their limited R&D funding on a project? Are universities equipped to support inventors in "going global" – a mantra explicitly laid out by South Korea. What additional legislative and regulatory frameworks must be considered when cross-border academic technology transfer takes place? What about data privacy and confidentiality?

Small economies face inherent scale limitations requiring access to international markets for viable commercialization. This necessity transforms commercialization from the domestically-focused geographical spillovers typically studied in the literature into cross-border activities involving multiple regulatory environments, languages, and market structures. Universities and inventors in such contexts must navigate substantially more complex strategic considerations.

Developing countries confront additional complications where domestic industry may lack sufficient absorptive capacity for university-generated knowledge. Markets may remain too nascent regarding firm capabilities, state-owned enterprises may crowd out private adoption, and the combination with small economy constraints compounds these difficulties. While existing literature examines researcher participation in global R&D networks, substantially more research is needed on cross-border technology transfer mechanisms and value chain integration. Unlike the European Union's common market framework, most developing countries must individually navigate entry barriers across neighboring markets, suggesting that successful academic commercialization strategies may require fundamentally different approaches than those developed for advanced economies.

7. Culture and mission perception

In addition to sectoral and country-specific variation, a third critical dimension shapes university innovation: the cultural and organizational factors within universities themselves. These internal dynamics explain why universities in the same country and sector can exhibit vastly different commercialization outcomes. The organizational identity and perceived mission of universities create varying approaches to the rules, practices, and relationship between academic research and commercialization activities. These differences extend beyond formal policies to include beliefs about appropriate university-industry engagement, the legitimacy of entrepreneurial activities, and the balance between academic output and economic impact. This sub-section examines three such components that provide a contextual overlay to the commercial impact of academic research: how public versus private governance introduce different commercialization incentives and constraints; the evolution and impact of formal infrastructure like TTOs and entrepreneurial university models; and the role of faculty and student attitudes in determining commercialization activity participation.

7.1 Public versus Private

Dating back to land-grant universities, the governance structure of public versus private universities shapes the rules, practices, and relationships underlying academic commercialization. In the United States, public universities comprise approximately 40% of research universities but account for over 60% of total university research expenditures, reflecting their distinct role in the innovation ecosystem. The literature reveals systematic differences in how these institutional types approach technology transfer and academic engagement, with implications for both the geography and channels of knowledge transfer.

Public universities face distinct constraints that influence their commercialization strategies. Welsh et al. (2008) document how U.S. public land-grant universities, given their mandate to serve state and regional development, played a pivotal role developing the agricultural biotechnology sector through industry collaborations. These institutions operate under state oversight and public accountability that emphasizes local economic development, agricultural extension services through USDA-funded experiment stations, and accessible education through programs like ROTC. This local-focused orientation shapes technology transfer policies that favor in-state licensees and regional partnerships, even when this reduces potential licensing revenues (Belenzon & Schankerman, 2009). Private universities, in contrast, typically enjoy greater autonomy in selecting commercial partners and face fewer geographic constraints in pursuing maximum financial returns from their intellectual property.

These institutional differences manifest in distinct spatial patterns of knowledge spillovers. Belenzon and Schankerman (2013) find that state border effects, the tendency for in-state inventors to disproportionately cite university patents even after controlling for distance, are significantly stronger for public universities than private ones. This pattern aligns with public universities' local development mandates and suggests that institutional governance structures shape both formal technology transfer mechanisms and informal knowledge diffusion channels.

7.2 Broadening Missions: TTOs and the Entrepreneurial University

Over the past four decades, universities have experienced fundamental shifts in their institutional arrangements and governance structures through the introduction of technology transfer offices following the 1980 Bayh-Dole Act in the United States and the emergence of the "entrepreneurial university" model that positioned universities as economic actors beyond traditional teaching and research roles. While the United States led in practical implementation of TTOs, European scholars theorized and formalized these concepts, with Clark (1998) and Etzkowitz (2003) coining "entrepreneurial university" based on observations of U.S. institutions, and European policymakers developing the "third mission" framework to explicitly outline university responsibilities for economic and social engagement.

The establishment of TTOs fundamentally restructured the institutional arrangement governing academic commercialization, shifting responsibility and control of academic outputs from the inventor to the university in the case of the U.S., and in largely opposite directions across Europe. Jensen and Thursby (2001) document how TTOs emerged as intermediaries to support disclosure, patenting, and licensing activities, while navigating often misaligned motives between university administration and faculty inventors. This formalization of technology transfer channels produced heterogeneous organizational responses and effects that varied significantly by institutional experience and capacity. Mowery, Sampat, and Ziedonis (2002) found that universities with established pre-Bayh-Dole commercialization support and industrial connections adapted more effectively to the new patent regime, while inexperienced "entrants" with less than five patents filed annually prior to 1980 often produced lower-quality patents measured by citation rates. The learning curve was substantial, with Mowery et al finding that new entrant universities required nearly a decade to develop effective commercialization capabilities, suggesting that accumulated expertise and organizational learning are essential for effective technology transfer. Henderson, Jaffe, and Trajtenberg (1998) raised more controversial concerns (which boiled down to a time horizon difference when measuring patenting effects compared with other studies), documenting that while university patenting surged post-Bayh-Dole, the average quality and importance of these patents declined significantly. Thursby and Thursby (2002) also provide empirical evidence that successful university commercialization depended on TTOs' ability to manage competing objectives between revenue maximization and broader university missions. Their analysis of total factor productivity revealed that while TTOs increased licensing output, much of this growth reflected increased faculty participation rather than improved organizational efficiency. Di Gregorio and Shane (2003) demonstrated that specific institutional policies, particularly equity investment provisions and royalty sharing formulas significantly influenced university spin-off formation rates. Siegel, Waldman, and Link (2003) provide qualitative evidence from interviews with 98 stakeholders revealing how organizational practices, incentive alignment, and boundary-spanning activities determine TTOs' effectiveness in facilitating technology transfer.

A decade later, yet concurrent to European adoption of university-owned IP and TTOs, the concept of the “entrepreneurial university” emerged as a theoretical framework to describe universities' increasing role in economic development. Van Looy et al. (2011) connect this entrepreneurial orientation to what the literature calls a "second academic revolution" during the 1990s that added entrepreneurial objectives as a third component, beyond traditional teaching and research duties, to the university mission. Clark (1998) first defined the entrepreneurial university as an institution actively seeking to innovate in its operations, external engagements, and integration of economic development with academic activities. European governments actively supported "third mission" underlying activities outlined by Meyer and Tang (2007), particularly during the early 2000s when many explicitly embedded "third mission" activities alongside TTOs. Geuna and Rossi (2011) outline the shift from inventor-based ownership to institutional ownership models of IP, motivated by perceived commercialization gaps with U.S. universities post-Bayh-Dole. However, Hvide and Jones (2016) find that Norway's own abolition of inventor rights alongside "third mission" responsibilities generated a 50% decline in university start-ups and patenting. These divergent outcomes highlight how the effectiveness of entrepreneurial university models depends critically on the alignment between formal policies, pre-existing institutional capabilities, and characteristics of the surrounding innovation ecosystem.

7.3 Open Innovation

The literature from the sociology of science provides an added contextual richness in understanding the role of institutional arrangements on university commercialization, particularly given what Sampat (2006) identified as an ongoing policy debate between the "public parts" of academic research (i.e., federal funding) and the "private parts" (commercialized university output). Bercovitz and Feldman (2007) further posit that universities are uniquely positioned to mitigate appropriation hazards for firms due to their mission-oriented incentives and limited market presence. While this chapter has acknowledged from its introduction that such notions (and hesitations) regarding the practicality of university research date back to the 1800s, more recent literature has conceptualized this tension. While Merton's original "open science" and Chesbrough's "open innovation" present a framework regarding the dual role of universities as knowledge creators and economic actors, they operate at different levels and with distinct concerns.

Robert Merton's conceptualization of "open science," developed from the 1940s established four principles framing university research: Communalism (knowledge should be shared), Universalism (truth claims evaluated on merit), Disinterestedness (pursuit of truth over personal gain), and Organized Skepticism (critical evaluation of claims). These "norms of science" positioned universities as producing public goods through open, cumulative knowledge building. However, the tension arises when considering the role of universities in undertaking commercialization. Dasgupta and David (1994) formalized how resource misallocation can occur when open science systems intersect with proprietary mechanisms, yet state that universities must navigate both. Cohen, Nelson, and Walsh (2002) show that "open science channels" in the form of publications, conferences, and informal channels remain the primary channel that university research impacts industry, and Sampat (2006) document how these open science channels/mechanisms continue to dominate knowledge flows from universities despite an increase in patenting and licensing activity. The institutional arrangements defined by Mertonian norms no longer appears adequate in addressing increasing commercialization activity, particularly as the Bayh-Dole Act and similar policies worldwide pushed universities towards more active technology transfer roles.

This gap regarding the role of the university thus gave rise to the open innovation literature, which emerged to help reconcile the tension between open science ideals and commercial imperatives, and to also offer a new way to conceptualize the role of universities. Chesbrough's (2003) framework suggested that firms should make use of external knowledge for their competitive advantage, especially in asking how firms can profit from university research. This perspective provided depth by identifying why certain institutional arrangements succeed or fail: Murray's (2010) distinction between "academic logic" and "commercial logic" explicitly outlined how and why universities must balance competing institutional pressures, while Fleming and Sorenson (2004) show that scientific publications serve as "search maps" that help industrial inventors avoid "dead ends" in technological development by means of increased knowledge spillovers, creating positive externalities that, thanks to Mertonian openness, increase commercial innovation efficiency.

What can we take from this evolving understanding? Hvide and Jone’s (2016) natural experiment provide an empirical test of these theoretical tensions. Their study of Norway’s abolition of the “professor’s privilege” (essentially Norway’s version of Bayh-Dole) resulted in a 50% decrease in university start-ups and patenting. While the authors acknowledge that scientists might be expected to follow Mertonian norms that emphasize the open access of ideas, their findings demonstrate that “innovation rights matter, even in universities.” This paradox reveals an interesting insight: modern institutional arrangements must recognize the university’s role in producing knowledge as a public good, yet the reality that property rights affect innovation outcomes. The failure of Norway’s reform suggests that effective commercialization cannot force corporate structures onto universities, but balance open science norms with incentive structures to motivate researchers while building institutional capacity for technology transfer.

7.4 Student and Faculty Attitudes

In extending the discussion from institutional arrangements to individual actors, it is worth examining the literature on faculty and student motives and incentives given they are ultimately the individuals undertaking the research at the heart of university commercialization. How do overarching institutional incentive structures impact university commercialization outcomes? And how do the trickle-down effects of national and institutional interventions influence their attitudes towards both research and commercialization? Perkmann et al. (2013) provide a useful distinction between the division of labor between institutions and researchers from the context of industry interaction which we argue can extend to the broader commercialization ecosystem. In "academic engagement" activities such as collaborative research and consulting, faculty researchers are the primary actors initiating and controlling the activities, with universities playing minimal roles. In "academic commercialization" through patenting and licensing (with the exception of academic entrepreneurship, although university resources/incentives remain paramount as documented by Lockett and Wright (2005)), however, universities take on a primary role through TTOs that with such follow-on activities, do not require researcher involvement, although it increases the probability of success according to Thursby and Thursby (2003). This division of labor reflects a division, and often a misalignment in motivation with researchers pursuing their own research agendas compared with revenue-motivated institutions.

Related literature reveals significant heterogeneity in researcher motivations across institutional contexts and disciplinary focus areas. Hartmann and Henkel (2020) surveyed over 1,400 AI researchers and found that while university and corporate researchers both value the ability to publish research, they differ in their perceptions of resource constraints and publishing restrictions, influencing whether to undertake university, at least in data-heavy fields, in academia or in the industry setting. Welsh et al. (2008) interviewed 84 biological scientists and found that faculty consistently face conflicts between institutional priorities and their own research objectives. The scientists reported that administrators often fail to understand the time-intensive nature of basic research, pressuring faculty to pursue short-term commercial outcomes that may compromise long-term scientific advancement.

The misalignment between faculty and administrative objectives become particularly pronounced in interactions with TTOs. Jensen and Thursby (2001) identify five outcomes from TTO activities (i.e., invention disclosures, patent applications, licenses executed, license income, and sponsored research), and document how TTOs prioritize revenue generation while faculty prefer sponsored research advancing their research agendas. Evidence can be shown through disclosure patterns where TTO personnel report less than half of inventions with commercial potential are disclosed, and those faculty refusing to disclose do so for philosophical reasons or to avoid publication delays averaging 6-8 months. Thursby and Thursby (2002) further elaborate on these motivational misalignments by surveying faculty and providing empirical evidence that identifies TTOs' reported frustration with faculty expectations often thought of as unrealistic, while faculty view TTOs as having too much focus on maximizing licensing revenue—counter to their priority on academic recognition and research funding. This tension is further exacerbated when institutional norms ignore faculty incentives as discussed at this point multiple times throughout this chapter regarding IP ownership, Bayh-Dole, and professor's privilege.

Di Gregorio and Shane (2003) analyze how royalty distribution policies create opportunity costs for faculty entrepreneurs. They find an inverse relationship between inventor royalty shares and startup formation. Specifically, a 10% increase in the inventor's share of royalties is associated with a 20% decrease in the rate of startup formation. This suggests that institutional policies designed to reward inventors through royalty shares might in fact discourage entrepreneurial activity by making licensing more attractive. The incentives towards academic entrepreneurship and subsequent success also depends on individual characteristics beyond institutional incentives. Amornsiripanitch et al. (2023) find that immigrant founders from academia are significantly more likely to start financially successful companies than native-born founders. Their analysis shows that immigrant academic entrepreneurs are 16% more likely to achieve an IPO or acquisition, with 75% of these immigrant founders holding advanced degrees from U.S. institutions. This places broader implications on human capital channels, suggesting that the composition of the faculty body directly influences both the quality and quantity of academic entrepreneurship. Collectively, these aforementioned findings demonstrate that successful university commercialization requires careful attention on the complex and often conflicting motivations of individual researchers, university administrators, and technology transfer professionals.

8. Conclusion

We've come a long way since Jaffe (1989). The causality question has been put to rest. We've established clearly that geographic proximity to universities benefits firms and regions, although global diffusion of knowledge is also important. The roles of university faculty and students as individuals, and of the universities themselves, in entrepreneurship and commercialization have increased significantly, and our understanding of how those processes play out has also deepened.

Much of the progress in recent years has come from better microdata (e.g. Umetrics) and new ways of linking data from different sources (e.g. patent citations to papers, affiliations and funding sources from papers, using Crunchbase and Pitchbook to identify university connections to start-ups). These data facilitate identifying the kind of natural experiments that resolved the causality issue, because events that are endogenous at the system level are often plausibly exogenous in terms of how they impact specific individuals. In principle data of this kind should also allow for better understanding of spillover mechanisms and better policy recommendations. There has been some progress of this kind on certain narrow issues, such as how gender disparities play out in academia, and how short-run funding changes affect short-run scientific output. More research of this kind, targeted to focus on the most policy-relevant questions, is feasible and could be a priority area for ongoing work.

Another important theme in recent work is the explicit use of network methods to understand how universities fit into the innovation system. These methods get at the background contributions by which universities fundamentally support the flow of knowledge, for example by playing key roles in the training and movement of postdocs who carry spillovers and act as connectors throughout the system. This building and facilitation of the spillover "plumbing" may be more important for global innovation in the aggregate than the direct effects seen in specific technology transfer events. These approaches are just beginning to exploit the potential created by large volumes of microdata and development of methods for large-scale network analysis. Hence this, again, is a promising area for near- and medium-term research.

A preponderance of the research has focused on the life sciences. This is due to a combination of the reality that life-sciences research is a majority of publicly funded university research, and the fact that invention and innovation are particularly easy to measure in this sector because of reliance on patents and the role of drug and medical device regulation in identifying and defining new products. We have learned a lot from this work, but much uncertainty remains as to how applicable the life-sciences model is to innovation in other sectors, both from the perspective of universities seeking to increase/improve technology transfer in other sectors, and of policy makers who want to understand the university/industry system in other sectors. The development of new methods based on large-language models and other natural-language processing algorithms offers the prospect for both better measures of innovation in non-life-science disciplines and industry sectors, and also better ways of linking innovation in these sectors to university research.

In terms of policy, most focus in recent decades has been on fostering technology transfer and commercialization. If we look at the policy choices around the world, there has been a convergence on the institution-ownership model. There is no doubt that this model 'works', i.e. that significant transfer of university technology to industry is occurring. But the details do matter. Different technology-transfer offices take different approaches; the vast majority of them are cost centers rather than profit centers for the universities, and different incentive systems for faculty do matter for the rate of innovation. These details are important both for the institutions and for the overall innovation system.

Despite the focus on technology commercialization, it is basic research that is the really irreplaceable aspect of what universities do, the often-unsung hero among all the activities universities pursue. This has kind of been taken for granted as policy has focused on fostering technology transfer, but as basic funding of universities becomes more precarious it is important to emphasize both the unique role of universities in performing basic research, and the background role they play in keeping knowledge growing and flowing around the world. Bedrock policies such as allowing endowment income to be tax free and providing significant funding of university fixed costs through overhead cost recovery can be thought of as socially efficient ways to subsidize the underlying innovation network creation and maintenance function of universities.

An important but understudied area is the role of universities in fostering innovation in less-developed countries, both historically and potentially in the future. Limited available research shows that borders do matter, and the need for researchers in less developed countries to overcome the barriers represented by national borders is an important practical and policy challenge. Such researchers do benefit from scientific publication of developed-world research, particularly if it is published on an open-access basis, but limited access to tacit knowledge and elite scientific networks, inadequate absorptive capacity, and a lack of complementary industrial capability all need to be overcome.

While we recognize the important regional and global benefits of universities, we should also acknowledge their contribution to social problems. Proximity effects and resulting agglomeration benefits create a fundamental tradeoff in fostering innovation. Highly innovative regions are the most productive place to send innovation investment, but this exacerbates regional inequality as the innovative rich get richer and other regions fall farther behind. Cass (2025) recently suggested that research funding agencies should impose quotas on the amount of funding going to each metropolitan area. Applicants in Boston would have to compete against those at Harvard and MIT, and the funding line would be lower for applicants from less successful regions. In the long run, talented scholars would have an incentive to move to those less competitive places because their chances of getting funded would improve. Because agglomeration effects are real, such a policy would decrease the overall productivity of public research, but it would also mitigate the extent to which that funding exacerbates regional inequality.

"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity…" (C. Dickens)

Universities today enjoy tremendous resources, and sit at the heart of key centers of historically unprecedented economic growth and wealth. At the same time, they are under attack as bastions of privilege in an increasingly unequal and troubled world. This contrast is in some ways inevitable, as the innovation system is intrinsically characterized by increasing returns to geographic scale and concentration. The forces by which universities generate wealth and prosperity also generate inequality. But if we address the inequality by strangling the goose, we will lose the golden eggs. Getting those eggs while mitigating inequality depends on efforts to understand the different pathways and mechanisms by which universities' creation and dissemination of knowledge affect the economy and society. Research on these 'real effects' has taught us much, but we still have a long way to go.

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Appendix: Articles analyzed for sectoral analysis

Article	Discipline	Which	Patent	Which	Econ. Sector	Which	Findings	Unit analysis	Single vs multi-sector	Life Sciences	Other
Jaffe (1989)	Yes	1) Drugs & Medical Technology 2) Chemical technology 3) Electronics, Optics, and Nuclear technology 4) Mechanical Arts 5) All Other	Yes	1) Drugs & Medical Technology 2) Chemical technology 3) Electronics, Optics, and Nuclear technology 4) Mechanical Arts 5) All Other	No	n/a	Statistically significant: 1) Drugs & Medical Technology 2) Chemical Technology Weakly significant: 3) Electronics/Optics/Nuclear Tech	discipline, patent	multi-sector	Yes	Electronics/Optics/ Nuclear Tech
Mansfield (1991)	No	n/a	No	n/a	Yes	1) Information processing 2) Electrical equipment 3) Chemicals 4) Instruments 5) Drugs 6) Metals 7) Oil	Firm use of academic research (economic sectors): 1) Drugs - highest, 27% products, 29% processes 2) Instruments - 16% products, 2% processes 3) Metals 13% products, 12% processes	economic sector	multi-sector	Yes	Instruments; Metals
Acs et al. (1992)	Yes	1) Drugs & Medical Technology 2) Chemical technology 3) Electronics, Optics, and Nuclear technology 4) Mechanical Arts	Yes	1) Drugs & Medical Technology 2) Chemical technology 3) Electronics, Optics, and Nuclear technology 4) Mechanical Arts	Yes	1) Drugs 2) Chemicals 3) Electronics 4) Medical	TECH AREAS 1) Electronics - corporate R&D and uni R&D both significant for PATENT outcome < only university R&D sig for INVENTION outcome 2) Mechanical arts - corporate R&D sig. for PATENT | uni R&D sig. for INVENTION 3) Drugs - efficiency measure - 2nd highest 3.3 innovations yielded	discipline, patent, economic sector	multi-sector	Yes	Electronics; Mechanical Arts

							per unit input after Mechanical at 3.5				
Rosenberg and Nelson (1994)	Yes	Biology; Chemistry; Geology; Mathematics; Physics; Agricultural science; Applied math/operations research; Computer science; Materials science; Medical science; Metallurgy; Chemical engineering; Electrical engineering; Mechanical engineering	Yes	Patent classes	Yes	Yale survey sectors: fluid milk, dairy, canned specialties, logging/sawmills, semiconductors, pulp & paper, farm machinery, grain mill, pesticides, processed foods, instruments, rubber, drugs, animal feed Mansfield survey industries: information processing, electronics, chemical, instruments, pharmaceuticals, metals, petroleum	PATENTS < universities sig. share in (1) medical sciences, (2) biotechnology, and (3) Electronics ^attribute to mission-oriented funding of NIH and DoD/DOE/NASA ^note patents less likely in engineering and service-oriented research	discipline, patent, economic sector	multi-sector	Yes	Agriculture and forestry
Mansfield (1998)	No	n/a	No	n/a	Yes	1) Drugs and medical products 2) Information processing 3) Chemicals 4) Electrical equipment 5) Instruments 6) Machinery (new in this update; replaces oil from Mansfield 1991) 7) Metals	1) Drugs and medical products - high dependence; 31% couldn't be developed vs earlier 27% | processes decreased from 29% earlier to 11% 2) Information processing - moderately strong increase in reliance (products 19% up from 11% | processes 16% up from 11%) 3) Instruments - strong improvement especially processes (product 22% up from 16 | processes 20% up from 2%)	economic sector	multi-sector	Yes	Information processing, Instruments
Jensen and Thursby (2001)	Yes	1) Science 2) Engineering 3) Medicine & Nursing 4) Agriculture 5) Other	No	n/a	No	n/a	(1) highest share of university TTO invention disclosure in 'Medicine and nursing' (44%), 'Engineering' (25%), Sciences (19%)	discipline	multi-sector	Yes	Engineering, Sciences

Thursby and Thursby (2002)	Yes	1) Biological sciences 2) Engineering 3) Physical sciences	No	n/a	No	n/a	biological sciences has greater market demand, more of a "seller's market"	discipline	multi-sector	Yes	n/a
Thursby and Thursby (2002)	Yes	1) Basic Sciences: Biology, Chemistry, Physics, Mathematics 2) Applied Sciences: Computer Science, Material Science, Medical and Health Science 3) Engineering Fields: Chemical Engineering, Electrical Engineering, Mechanical Engineering	No	n/a	Yes	Yes 34 industry groupings aggregated using SIC a) 34 ISIC groups aggregated at the 2- or 3-digit level b) some analyses disaggregated into 64 industries at ~3-SIC level	Most impactful disciplines - SURVEY (NO STAT SIGNIFICANCE) (pg 10-13, Table 3) 1) Materials Science - >50% importance 15 of 33 industries (strong in chemicals, metals, electronics, machinery, transportation) 2) Computer science (important) >50% in glass, printing/publishing, communications equipment, search/navigation equipment, aerospace, computer 3) Chemistry - broadest BASIC SCIENCE impact ≥50% importance in: food, petroleum, metals, several chemical industries including drugs FIELD SPECIFIC IMPACT 1) Biology - critical 64% pharmaceuticals; minimal elsewhere 2) Physics - important semiconductors (62%); limited elsewhere 3) Medical/Health Science - strong drugs and medical equipment; limited elsewhere SECTORS BY PUBLIC RESEARCH IMPORTANCE 1) Pharmaceuticals (drugs) - highest overall |	discipline, economic sector	multi-sector	Yes	Disciplines: Material science, Computer science Patent: Physics Economic sectors: Semiconductors, Aerospace

							unique that customers/manufacturing less important than public research | 58% use public research new projects | 73.5% rate publications as important -> (pg 6-8, 10-12) 2) Semiconductors (pg 6, 11) - 50%+ for new project ideas | 62% report physics important | 60% rate publications important 3) Aerospace 50% +				
Mowery et al. (2002)	No	n/a	Yes	1) Biomedical patents 2) Nonbiomedical patents	No	n/a	Biomedical patents - consistently highly cited, regardless of university type | thus, no evidence learning to patent Nonbiomedical patents - evidence of "learning" post-Bayh-Dole, closing quality gap between incumbents and surpassing controls	patent	single - sector : biomedical	Yes	bio-medical patents
Mowery and Ziedonis (2002)	No	n/a	Yes	1) Biomedical patents 2) Nonbiomedical patents	No	n/a	Biomedical dummy is positive and statistically significant < consistently highly cited, more so than non-biomedical patents -> statistically significant citation advantage ^biomedical patents dominate university patents post-Bayh-Dole in quantity and quality, but also more specialized	patent	single - sector : biomedical	Yes	n/a

Adams (2002)	Yes	Science disciplines: astronomy, chemistry, physics, other physical sciences; computer science, mathematics and statistics; atmospheric sciences, earth sciences, and oceanography; agriculture, biology, and medicine Engineering disciplines: aeronautical, chemical, civil, electrical, mechanical, and other engineering	No	n/a	Yes	Chemicals (SIC 28) Machinery (SIC 35) Electrical equipment (SIC 36) Transportation equipment (SIC 37)	references studies showing biotech relies more on academic spillovers and computing on industrial spillovers	discipline, economic sector	multi-sector	Yes	computing
Di Gregorio and Shane (2003)	No	n/a	No	n/a	Yes	1) Food, drink and tobacco 2) Textiles 3) Wood 4) Paper and printing 5) Chemicals 6) Plastics 7) Non-metallic minerals 8) Basic metals 9) Fabric metal products 10) Machinery 11) Electrical 12) Transport 13) Other	1) Chemicals 2) Machinery	economic sector	multi-sector	Yes	Machinery

Audretsch et al. (2005)	Yes	1) Natural sciences 2) Social sciences	No	n/a	Yes	1) Software 2) E-services 3) E-commerce 4) Computer and hardware 5) Telecommunication 6) Biotechnology 7) Medicine and life science 8) Media and entertainment 9) High-technology	Statistically significant: (1) Biotechnology and Media Weakly significant: (2) Medical devices	discipline, economic sector	multi-sector	Yes	Media
Audretsch and Lehmann (2005) Germany	Yes	1) Natural sciences 2) Social sciences	No	n/a	Yes	Software Service Media and Entertainment Hardware/Technology Biotechnology/Medical Technology (Biotec/Medtec)	Statistically significant: 1) Natural Sciences - natural science students increase probability local IPO for Hardware/Technology, Biotechnology/Medical Technology, and publications for Hardware/Technology 2) Social Sciences - students positively influence all sectors	discipline, patent, economic sector	multi-sector	Yes	Hardware/technology
Woodward et al. (2006)	Yes	Engineering Physical Sciences Geosciences Mathematics and Computer Sciences Life Sciences (including agricultural, biological, medical, and other life sciences) Science and Engineering Technologies	No	n/a	Yes	27 high-technology manufacturing industries based on BLS R&D intensive industries grouped into 5 two-digit SIC categories SIC 28: Chemicals and Allied Products (combines SICs 281, 282, 283, 284, 285, 286, 287, 289) SIC 35: Industrial Machinery and Equipment SIC 36: Electronic & Other Electrical Equipment SIC 37: Transportation Equipment	ECONOMIC SECTORS (additional dollar spent on university R&D on the probability of a new plant) SIC 28 (Chemicals): Significant at $p < 0.05$ (coefficient = 0.0021**) SIC 36 (Electronic & Other Electrical Equipment): Significant at $p < 0.01$ (coefficient = 0.0052***) SIC 37 (Transportation Equipment): Significant at $p < 0.01$ (coefficient = 0.0046***) SIC 38 (Instruments and Related Products): Significant at $p < 0.01$ (coefficient = 0.0035***)	discipline, patent, economic sector	multi-sector	Yes	electronic & other electrical equipment, transportation equipment, instruments and related products

						SIC 38: Instruments and Related Products					
Bercovitz and Feldman (2007)	No	n/a	No	n/a	Yes	Pharmaceutical/biotechnology (9 companies) Communication/telecom equipment (10 companies) Electronics (8 companies) Energy (6 companies) Minerals/mining (6 companies) Miscellaneous (6 companies, omitted category)	ECONOMIC SECTORS Statistically significant 1) Pharmaceuticals/Biotechnology - increased allocation R&D budget to exploratory university research projects *Electronics have a negative statistically significant effect in university interactions	economic sector	multi-sector	Yes	No
Abramovsky et al. (2007) GREAT BRITAIN look at CMS study	Yes	Biology Chemistry Physics Computer science Materials science Medical and health science Chemical engineering Electrical engineering Mechanical engineering Mathematics	No	n/a	Yes	Pharmaceuticals Chemicals (excluding pharmaceuticals) Machinery Electrical machinery TV, radio and communications equipment Motor vehicles	ECONOMIC SECTORS Statistically significant 1) Pharmaceuticals - positive effect of Chemistry, Biology, and Medical departments on local pharma R&D establishments 2) Chemicals - Materials Science departments on chemical R&D establishments 3) Machinery - Materials Science dept. on Machinery R&D establishments 4) Electrical Machinery - Electrical Engineering & Computer Science 5) TV & Radio Equipment - positive effect graduate students (no specific depts)	discipline, patent, economic sector	multi-sector	Yes	Machinery, electrical machinery, tv & radio equipment
Welsh et al. (2008)	Yes	1) Agricultural biotechnology 2) Biological sciences	No	n/a	No	n/a	authors study agricultural biotechnology because where they claim most university-industry collaboration occurs	discipline	single - sector biotechnology	Yes	n/a

Andersson et al. (2009)	Yes	1) Technical research specialties 2) Non-technical research specialties	No	n/a	No	n/a	Statistically significance (1) new universities have larger patenting effects than old, (2) technical researchers at new universities have the strongest effect	discipline	Multi-sector	n/a	n/a
Van Looy et al. (2011)	Yes	1) Arts & Humanities 2) Engineering 3) Sciences 4) Life Sciences	No	n/a	Yes	1) Food 2) Environment 3) Pharmaceuticals & Biotechnology 4) ICT 5) Machinery and equipment 6) Consultancy	1) Only engineering had a negative effect on patents; authors don't directly explain this counterintuitive finding; surprising given paper cited studies showing engineering departments stimulate entrepreneurial activities	discipline, economic sector	multi-sector	n/a	*engineering negative effect on patents?
Geuna and Rossi (2011)	No	n/a	No	n/a	No	n/a	Mentions a leveling off of biotechnology patenting post IPR changes in Europe	NONE	NONE	Yes	n/a
Cowan and Zinovyeva (2013)	Yes	1) Engineering 2) Sciences 3) Medicine, Chemistry and Pharmacy 4) Veterinary and Agriculture	No	n/a	Yes	1) Industry (manufacturing) 2) Services 3) Agriculture 4) Construction	Disciplines/Schools: 1) Medicine, chemistry and pharmacy - described as having "the strongest effects" 2) Veterinary and agriculture - also noted as having strong effects ^strongest positive effects on regional innovation	discipline, economic sector	multi-sector	Yes	Veterinary and agriculture
Belenzon and Schankerman (2013)	No	n/a	Yes	1) Biotechnology 2) Chemicals 3) Pharmaceuticals 4) Medical Equipment 5) Engineering 6) Electronics 7) Information Technology	No	n/a	Statistically significant: Biotechnology Chemicals Pharmaceuticals Medical Equipment Weakly significant: Engineering	patent	multi-sector	Yes	engineering

				8) Telecommunications							
Scandura (2016)	No	n/a	No	n/a	Yes	Manufacturing sectors: Manufacturing of motor vehicles, trailers & semi-trailers Manufacturing of medical, precision & optical instruments Manufacturing of fabricated metal products Manufacturing of radio, TV & communications equipment Manufacturing of chemicals and chemical products Manufacturing of rubber & plastic products Manufacturing of computers Manufacturing of electric machinery & apparatus Manufacturing of other non-metallic mineral products Manufacturing of other transport equipment Service sectors mentioned: Defense/Public administration and defense Retail trade Other business activities (legal, accounting, intellectual property) Hotels & restaurants Computer & related activities	Manufacturing Figure - < not mentioned, but visually top 3 sectors firms willing to participate with universities when treated Manufacturing of motor vehicles - largest difference shown Manufacturing of medical products Manufacturing of metal products	economic sector	multi-sector	n/a	Manufacturing of motor vehicles, medical products, and metal products

						Research & development					
Ahmadpoor and Jones (2017)	Yes	185 Web of Science field classifications for Science and Engineering papers	Yes	388 USPTO technology classes	No	n/a	PATENT CLASS pg 1 - Closest to paper-patent boundary (strongest connections): Combinatorial chemistry, molecular biology, superconducting technology, artificial intelligence DISCIPLINES Closest (strongest connections): Nanoscience and nanotechnology, materials science and biomaterials, computer science hardware and architecture	discipline, patent	multi-sector	Yes	Patents superconducting technology, artificial intelligence Disciplines computer science hardware and architecture
Hvide and Jones (2018)	Yes	1) Science and engineering faculty 2) Social sciences and humanities (as control)	Yes	Patents at 1-digit IPC code	Yes	1- and 2-digit NACE use Eurostat sectoral classification by technological intensity	PATENTS The technology-class level analyses showed similar results to aggregate analyses, with "somewhat greater precision at the technology-year level"	discipline, patent, economic sector	multi-sector	n/a	n/a
Bikard and Marx (2020)	Yes	251 scientific fields from Web of Science + use of Medical Subject Headings (MeSH) keywords (27,255 categories) + Microsoft Academic Graph (185,600 topics) for topic-based classification	Yes use to match to papers for topic-to-patent threshold mappings	Patent subclasses for patent-paper mappings	No	n/a	no differential findings by sector	discipline	multi-sector	n/a	n/a

Babina et al. (2020)	Yes	1) Science 2) Biology/Medicine/Pharmaceutical 3) Engineering 4) Liberal Arts/Other	No	n/a	Yes	"high-tech sectors" defined using NSF classification of high-tech NAICS codes	PATENTS	discipline, economic sector	multi-sector	Yes	engineering
Tartari and Stern (2021)	Yes	1) Natural sciences 2) Social sciences 3) Humanities	No	n/a	Yes	Broad sectors: Local, Traded, Resource Intensive High-tech sectors: Biotech, E-commerce, IT, Medical devices, Semiconductors	Statistically significant: (1) Natural sciences drive entrepreneurship quantity and quality, (2) Social science PhD students increase entrepreneurship quality but with negative effect on Master and Bachelor	discipline, economic sector	multi-sector	n/a	n/a
Marx and Hsu (2022)	Yes	251 scientific fields from Web of Science Additional Biotechnology vs Non-biotechnology life sciences vs Non-life sciences analysis	No	n/a	No	n/a	Descriptive: (1) Most popular fields for star commercialization Biochemistry and molecular biology (13.2%), Chemistry (6.5%), Engineering, electrical and electronic (5.1) Statistically significant (2) Biotechnology (discipline) - having star commercializer on paper increases startup commercialization likelihood; (3) Non-Biotechnology Life Sciences (discipline) - star authorship, prior star work, interdisciplinary significant	discipline	Multi - sector	Yes	Engineering, electrical and electronic
Andrews (2023)	No	n/a	Yes	Patent classes	Yes	Manufacturing sector Agricultural sector	no differential findings by sector	patent, economic sector	multi-sector	n/a	n/a

Arora et al. (2023)	Yes	25 OECD natural science subfields: Mathematics, Computer and information sciences, Physical sciences and astronomy, Chemical sciences, Earth and related environmental sciences, Biological sciences, Other natural sciences, Civil engineering, Electrical eng, electronic eng, Mechanical engineering, Chemical engineering, Materials engineering, Medical engineering, Environmental engineering, Environmental biotechnology, Industrial biotechnology, Nano-technology, Other engineering and technologies, Basic medical research, Clinical medicine, Health sciences, Agriculture, forestry, fisheries, Animal and dairy science, Veterinary science, Other agricultural science	Yes	Patent subclasses	Yes 7 SIC-based industry classification codes	1) Computer, IT, and software 2) Electronics and semiconductors 3) Machinery, equipment, and systems 4) Life sciences 5) Telecommunications 6) Transportation 7) Others	Statistically significant: (1) Life Sciences (economic sector) - firms collaborate with universities to acquire startups rather than competing, (2) Electronics/semiconductors (economic sector) - some significant effect of public knowledge as complementary Weakly significant: (3) Machinery, equipment, systems (sector) - modest knowledge transfer of public knowledge	discipline, patent, economic sector	Multi - sector	Yes	Electronics/semiconductors, Machinery, equipment, systems
Babina et al. (2023)	Yes	17 departments used as basis for disciplines (no complete list provided)	Yes	Patent technology classes mapped to CFDA codes ^maps CFDA codes to 1 patent class, corresponding CFDA code most common CFDA for a	Yes	6-digit NAICS codes focusing on 146 high-tech industries (high-tech defined by NSF)	(1) in unreported analysis by field, found effects from all outcomes to come from hard sciences, such as engineering and biomedical research, "rather than by the humanities"	discipline, patent, economic sector	Multi - sector	Yes	engineering

				researchers with patent in that class							
Beine et al. (2024)	Yes	1) STEM majors 2) non-STEM majors	No	n/a	No	n/a	Statistically significant: (1) STEM majors have the highest rate of foreign master student start-ups Weakly significant: (2) Non-Stem majors and Top 5 majors more likely relative to control to form start-ups	discipline	multi-sector	n/a	n/a
Bergeaud et al. (2024)	Yes	Uses k-mean clustering to categorize disciplines	Yes	IPC classes at 3-digit level (123 categories) IPC classes at 4-digit level (641 categories)	Yes	732 NACE industries	Highest proximity cases: Biodiversity project → biotech R&D (7219Z), pharmaceutical manufacturing (2120Z), fertilizer manufacturing (2015Z) Space exploration → aircraft machinery (3030Z), engineering studies (7112B), organic chemicals (2014Z) Electronic miniaturization → electronic components (2611Z), communication equipment (2630Z), plastics (2016Z)	discipline, patent, economic sector	multi-sector	Yes	Aircraft machinery, engineering studies, electronic components, communication equipment, plastics
Rezaei and Yao (2024)	Yes	Uses SciBERT to classify subject of neuroscience grants + use GPT-4o-mini for multi-label classification	Yes	NLP-based, define neuro-technology groups looking at CPC titles containing keywords (220 groupings)	Yes	1) Information Technology 2) Healthcare 3) B2B (Business-to-Business) 4) B2C (Business-to-Consumer) 5) Energy 6) Financial Services 7) Materials 8) Resources also use Pitchbook 59 technology verticals	Disciplines: BI grants are 4x more likely in Computer Science, 3.4x in Engineering, 4.5x in Physics, 3.2x in Mathematics compared to non-BI grants Sectors: 88% spinouts in health sciences sector, 8% IT	discipline, patent, economic sector	single-sector: neuroscience	Yes	Computer Science, Engineering, Physics

Lerner et al. (2025)	Yes	Biomedical research (authors where 50% or more publications linked to PubMed)	Yes	35 subgroups of WIPO patent classifications	No	n/a	[to fill]	discipline, patent	single - sector : biom edical	Yes	n/a