NBER WORKING PAPER SERIES

ACCELERATING INNOVATION ECOSYSTEMS:
THE PROMISE AND CHALLENGES OF REGIONAL INNOVATION ENGINES

Jorge Guzman
Fiona Murray
Scott Stern
Heidi L. Williams

Working Paper 31541
http://www.nber.org/papers/w31541

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
August 2023

We are enormously grateful to Erwin Gianchandani, Graciela Narcho, Danny Goroff, Rebecca Shearman, Thyagarajan Nandagopal, Dmitri Perkins, Geoff Brown and other staff at the National Science Foundation for their time and support of work related to this paper through NSF grant #2232647 (EAGER: Place-Based Innovation Policy Study Group) to the National Bureau of Economic Research (NBER), and Phil Budden, Maryann Feldman, Ben Jones, and Josh Lerner for helpful comments and suggestions. This paper draws in part from frameworks and activities developed within the MIT Regional Entrepreneurship Acceleration Program (REAP), of which two of the authors (Murray and Stern) are co-founders and faculty directors, and in which one author (Guzman) has taught and provided research support. We would like to thank the MIT REAP staff and faculty, including Sinan AbuShanab, Bill Aulet, Kelly Becker, Phil Budden, David Capodilupo, Georgina Campbell, Michael Cusumano, Travis Hunter, Mollie Laffin-Rose Agbiboa, Shari Loessberg, and Sarah Jane Maxted for insight and contributions that informs this work. Also, while Murray, Stern and Guzman have received supplementary compensation from MIT REAP, the REAP program was not involved with and did not provide direct support in the production of this manuscript. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

At least one co-author has disclosed additional relationships of potential relevance for this research. Further information is available online at http://www.nber.org/papers/w31541

Accelerating Innovation Ecosystems: The Promise and Challenges of Regional Innovation Engines
Jorge Guzman, Fiona Murray, Scott Stern, and Heidi L. Williams
NBER Working Paper No. 31541
August 2023
JEL No. D78,L2,O3

ABSTRACT

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.

Jorge Guzman
Columbia Business School
Kravis Hall, 975
655 W 130th St
New York, NY 10027
and NBER
jag2367@gsb.columbia.edu

Fiona Murray
MIT Sloan School of Management
100 Main Street, E62-470
Cambridge, MA 02142
and NBER
fmurray@mit.edu

Scott Stern
MIT Sloan School of Management
100 Main Street, E62-476
Cambridge, MA 02142
and NBER
sstern@mit.edu

Heidi L. Williams
Department of Economics
6106 Rockefeller Center, Office 328
Dartmouth College
Hanover, NH 03755
and NBER
heidi.lie.williams@dartmouth.edu

1. Introduction

The productivity and impact of investment in research depends not only on *which* projects are undertaken and *how much* money is spent, but also on *where* those projects are located (Jaffe, 1986; Feldman, 1994; Gruber, Johnson, and Moretti, 2022). The location of the research enterprise impacts the productivity of individual researchers (e.g., their rate of research output per dollar of expenditure) as well as the impact of a given piece of research on follow-on applied research and development activities with the potential for tangible economic and social benefits (Audretsch and Feldman, 1996; Furman and MacGarvie, 2007). As a consequence of these locational differences in research productivity, research investment (particularly but not limited to private investment) and innovation outputs are highly skewed: for example, by 2015, the San Francisco Bay Area accounted for more than 17% of all patented inventions (and over half of all venture capital investment), despite being about 2% of the U.S. population (Forman, Goldfarb, and Greenstein, 2016; USPTO, 2015; Delgado and Murray, 2022).

This striking variation in both the level and productivity of research and innovation across different geographic areas has motivated a significant body of research on the drivers and consequences of place-based innovation "ecosystems" (Nelson, 1993; Feldman, 1994; Edquist, 1997; Furman, Porter and Stern, 2002; Bresnahan and Gambardella, 2004). By innovation ecosystem, we mean the interconnected set of institutions – universities, corporations, government, start-ups, and investors – within a geographic region whose connectivity allows each organization and researcher in that region to leverage the knowledge, resources, and specialized capabilities of other institutions and individuals within that location (Budden and Murray, 2022). The place-based innovation ecosystem as a unit of analysis has gained more attention as evidence has accumulated on the key role of geographically proximate innovation-driven entrepreneurs in shaping the level and rate of commercialization of publicly funded research (Aulet and Murray, 2013; Stam, 2015; Fehder, et al. 2023), and the historically dismal performance of regional venture capital efforts aimed at initiating a more inclusive, geographically distributed approach (Lerner, 2009, 2013).

An ecosystems perspective on the role of location in innovation suggests that the innovative productivity of a given researcher depends not simply on the quality of that researcher but also on the degree to which researchers in that location are able to build on each other's knowledge, invention, and discoveries, and participate in different stages of commercialization. Perhaps more importantly, this approach suggests that the precise configuration of the overall system – how different elements of the ecosystem interact, the rules and norms that govern interactions – may influence the overall rate of innovative productivity within a given ecosystem. For example, an ecosystem characterized by shared research infrastructure that allows university and private sector researchers to collaborate and learn from one another might be able to realize a higher rate of innovative output than an ecosystem that expends an equivalent level of investment but where researchers operate in institutional siloes.

Despite an increasing body of theoretical and empirical research on the role and impact of innovation ecosystems, the historical criteria for the vast majority of Federal science and research investments has largely abstracted away from place-based criteria in the funding and management of research programs. For example, the standard NSF Merit Review Criteria focuses on two core dimensions – Intellectual Merit and Broader Impact – to ensure a "fair and level" playing field for America's science and engineering researchers. By design, this NSF Merit Review Criteria provides neither an explicit advantage nor an explicit penalty based on the location of a given research team or whether a particular geography offers a particularly supportive environment for commercialization and economic impact.

This historical neglect of location has now ended. Over the past decade, the U.S. Federal government started to undertake increasingly large "experiments" with place-based approaches to innovation policy, such as the Department of Commerce i6 Challenge grant in the early 2010s. As well, an increasing number of place-based innovation policies programs around the world – such as the European Union's "Smart Specialization" program, the U.K.'s Innovation Accelerators program as part of its "leveling up" agenda, and Canada's Superclusters awards – have gained increasing prominence and attention as a means for realizing the benefits of innovation in a more inclusive manner. Gruber and Johnson (2019), along with other policy advocates, synthesize the implications of these experiences by suggesting that a potentially powerful approach to "jump-start" America is to center place-based innovation policy interventions as part of a broader strategy for inclusive economic development. Specifically, they argue that in ecosystems outside the "top tier," it should be possible to more powerfully realize the impact of Federal research investments through additional programs and initiatives that nurture and accelerate innovation ecosystems (Gruber and Johnson, 2019). Many of these proposals were authorized and funded as part of the 2022 Inflation Reduction Act and the CHIPS and Science Act.

The Regional Innovation Engines (RIE) program, currently being launched by the National Science Foundation (NSF) newly created Technology, Innovations and Partnerships (TIP) Directorate, is one of the most prominent initiatives resulting from this new legislation. The RIE program intends to catalyze a broad base of innovation ecosystems throughout the U.S. and "significantly [expand] our Nation's innovation capacity by investing in key areas of national interest and economic promise in every region of the United States." The NSF RIE program focuses specifically on prioritizing "U.S. geographic regions that do not have well-established innovation ecosystems" and commits up to $160 million per region over twelve years to allow local stakeholders to design and develop a regional innovation cluster (NSF, 2022).

The purpose of this paper is to understand the logic, challenges, and opportunities for innovation "Engines." Our goal is to identify both the rationale and the potential pitfalls associated with place-based strategic interventions whose aim is to "wire" or "re-wire" an innovation ecosystem in order to enhance innovative productivity and impact.[1] To accomplish this objective, we begin by synthesizing the broad potential for place-based innovation policy and the Engines approach. While there have been a variety of descriptive analyses of the current Engines program and the hoped-for impact of these interventions, ours is the first systematic assessment of the economic literature on innovation ecosystems and the way it relates to the Engines approach.

We then delve more deeply by considering the underlying "logic" model for an Engine. Specifically, and in accordance with the framework developed in Jones and Summers (2022), we

[1] The authors were part of an ad hoc Study Group convened during Fall 2022 under an NSF EAGER grant that included both academic researchers with expertise in innovation ecosystems, innovation policy, and program design and evaluation, as well as personnel within the newly established NSF TIP directorate. While the paper draws on the learning of that study group, this paper exclusively represents the views of the authors and does not represent views or policy positions of NSF personnel, the TIP directorate, or other study group participants.

highlight the potential of an Engine intervention to increase the innovative productivity of an entire ecosystem through modest but real improvements in the conditions supporting a regional innovation ecosystem. Such small changes have the potential to offer an outsized impact in terms of social returns. However, this logic model also suggests that, in order to realize this potential return, the Engine must be designed to remove a key bottleneck, leverage a previously under-tapped latent capability, or introduce a new capacity to address an economically significant weakness in the current state of the regional innovation ecosystem.

The perspective that an Engine intervention must be fit for purpose and aligned with the strengths and weaknesses of the region in which it is implemented motivates an in-depth analysis of the conditions that must be present within a given innovation ecosystem in order to realize the promise of the logic model.[2] Consistent with the need government is to "set the table" (Lerner, 2009), place-based innovation policy is more likely to be realized more effectively if it is based on a clear logic model of how a policy such as an Engine intervention is likely to induce change.

Critically, it is not enough to simply assume that the logic model will hold in the presence of Federal investment in Engines. Instead, the promise of an Engines approach requires a theory of "change" in the ecosystem – how the program will induce changes in behavior, and also what changes in access to resources, capabilities and knowledge must actually occur in order for the program to reach its objectives. This analysis highlights the importance of overcoming three distinct and interrelated set of challenges: stakeholder engagement, holistic ecosystem assessment, and implementable strategic choice.

Regional stakeholders are critical for facilitating the behavioral changes underlying an Engine. Indeed, Feldman's (2014) emphasis on the critical role of regional champions highlights the importance of supporting those individuals and organizations who might encourage change in many stakeholder groups. But stakeholder engagement will only be effective if those stakeholders have a shared (and holistically accurate) assessment of their ecosystem and how particular their own and others' interventions might enhance its performance. And, even if stakeholders are engaged and a promising set of investments is identified, realizing the potential

[2] The analysis of these conditions builds on an emerging body of both academic research and practitioner insight, including the experiences of a subset of the authors within MIT REAP.

of an Engine depends on effective strategic choice and implementation. Many interventions fail due to the challenges associated with making strategic choices and thus choosing what not to do within a region (or at least what activities are de-emphasized to make space for others).

By outlining the necessary conditions for place-based innovation policy and ecosystem support, and the unique individual characteristics that drive successful implementation, we are able to provide insight into the most critical factors region (and the Federal government) might consider as they choose and implement an Engines approach. While our analysis focuses primarily on the analysis of Engine in isolation (i.e., a specific regional intervention in a particular place), our analysis can also inform the design and implementation of an Engines portfolio at the Federal level. Finally, our analysis has implications for the real-time assessment and course-correction of an Engines program over time, as well as the evaluation of individual regional interventions.

2. The Economics of Regional Innovation Engines

The Promise of Place-Based Innovation Policy

A central contribution in the academic literature on the economics of innovation has been to document that there is a substantial localized and place-based component of R&D spillovers (Jaffe et al., 1993; Audretsch and Feldman, 1996; Kerr and Kominers, 2015; Myers and Lanahan, 2022). Yet, somewhat surprisingly, the design of Federal innovation policy has not typically emphasized the role of place. While the wider U.S. innovation system has always been a highly decentralized project of publicly funded scientific and engineering research across a wide variety of institutions and domains (Mowery and Rosenberg, 1993; Rosenberg and Nelson, 1994), Federal innovation policy has, by and large, focused on broad investments in research capabilities, support for historically located national labs and the development of specific technological trajectories. The localization of innovation has largely been an (unintended) consequence of these broader policy efforts rather than an intentional choice made by design.

The presence of geographically mediated knowledge spillovers suggests that the returns to research investments depend not only on the effort of individual researchers, but also on how these researchers, entrepreneurs and organizations are situated and engaged within an overall innovation ecosystem (Nelson, 1993; Feldman, 1994). While the innovation ecosystems approach was first conceptualized at the national level (Nelson, 1993), the fine-grained nature of geographic spillovers has prompted researchers to focus more closely over time on the scope of *regional* innovation systems. The defining feature of a regional innovation ecosystem is the presence of distinct institutions, resources, and capabilities that are interdependent on one another, that combine to shape the regional comparative advantage of that region, and which make the innovative productivity of any given individual or organization substantially dependent on the choices and activities of others within these systems. They do not necessarily follow convenient political boundaries (of states, cities, or towns) but rather follow the logic of the particular organizations whose interdependencies drive regional comparative advantage (Budden and Murray 2018; 2019).

Gruber and Johnson (2019) and Gruber, Johnson, and Moretti (2021) synthesize the potential value of this approach by emphasizing the importance of "latent capacity" in innovation production and performance across places. They argue that because there are economically significant non-linearities in the marginal return to scientific and research capabilities, there may be higher social returns to upgrading innovation ecosystems in the "middle tier" of capabilities rather than simply focusing even more heavily on the "top" innovation ecosystems in the United States (such as Boston and Silicon Valley). More precisely, their argument is that while the productivity increases from scientists co-locating with other scientists are roughly linear, the cost increases due to congestion, increasing costs of living, and increasing costs of production are such that on net the biggest return to national innovation may be realized by investing in many, rather than just a few cities, and in mid-size, not supersized, cities.

A different line of reasoning emphasizing inequality and the nature of opportunity arrives at a similar conclusion albeit from a different premise. A variety of evidence suggests that innovation creates a divergence in labor market outcomes due to skill-biased technical change (e.g., Berman et al., 1998; Fernandez, 2001) and predominantly negatively impacts individuals working in less skill-intensive jobs (Acemoglu, 2003). Skill-biased technical change has furthermore been argued to be a key driver of growing regional inequality (Hsieh and Moretti, 2019; Moretti, 2012): regions with high levels of entrepreneurship, innovation, and venture capital investment such as Silicon Valley and Boston have seen high levels of productivity and economic growth, while regions focused on more traditional manufacturing industries such as those in the Rust Belt have seen economic failure and loss of income (Glaeser et al, 2018). Yet, the traditional solutions to skill-biased displacement – workforce training programs – implicitly address displacement of jobs within regions, not across them. The fact that inequality manifests itself as a divergence in spatial outcomes suggests instead considering alternative interventions that hold the potential to enhance regional growth opportunities.

The potential for government in enabling such regional growth opportunities is important to assess against the historical development of today's most innovative regions (Lerner, 2013).[3] Two recent studies provide important evidence in this regard. First, Kantor and Whalley (2022) examine the impact of Federal research investment during the U.S. Space Race, and find that, relative to other similar regions that the government considered but did not ultimately invest in, regions that were the target of Space Race contracts experienced significantly higher economic growth, innovation, and population growth over time. Similarly, Gross and Sampat (2023) examine the long-term impact of funding from the U.S. Office of Scientific Research and Development (OSRD) during World War II, finding that regions that received this funding are now home to some of the largest U.S. technology clusters. Simply put, interventions of Federal research investment into a region have the potential to induce large changes in the long-term innovation and economic performance outcomes for that region. The question then becomes what types of targeted policy interventions take advantage of this potential.

Put another way, realizing the promise of place-based innovation policy requires understanding the conditions under which ecosystem acceleration programs are likely to succeed, the types of programs and initiatives that might be particularly useful in a given environment, and identifying the resources and capabilities that are required for effective implementation. While seemingly straightforward, these are precisely the concerns emphasized by Lerner (2009) in his recounting of the challenge of place-based policies to encourage regional entrepreneurship. Specifically, Lerner (2009, 2013) documented how efforts in the early 2000s to establish government-supported venture capital led to an array of failures, in large part because, in their haste to hand-out startup capital, government officials neglected efforts to 'set the table' such as

[3] Lerner (2013) states "[A] review of the history of Silicon Valley and several of the pioneering venture capital groups finds that reality is far more complex than some of our more libertarian entrepreneur friends might have us believe. In each case we look at, the role of the government as an initial catalyst was critical in stimulating the growth of the region, sector, or firm."

ensuring the translation of knowledge from academia to industry, setting up appropriate legal frameworks, and educating and developing local entrepreneurial talent. In his words, "entrepreneurial activity does not exist in a vacuum" (Lerner, 2013).

Of course simply choosing an effective policy intervention is not enough. As highlighted by Feldman (2014), while policies and regional advantages matter, it is ultimately the commitment of enterprising local individuals and their communities that creates the most significant differences in the prosperity of innovative regions (see also Feldman and Francis, 2003), including the transformation of the culture and engagement (i.e., the 'relational contract') of those in the location. She argues that regional stakeholders, including local "champions," are key to re-shaping an ecosystem as a whole.

Federal Place-Based Innovation Initiatives: The Engines Approach

The growing appreciation for the way place-based innovation determines economic outcomes has precipitated a blossoming of new policy initiatives. In Europe, the European Commission launched the Partnerships for Regional Innovation program as an integral part of its €95.5 billion European Innovation Fund. This fund seeks to invest in 74 distinct regions in Europe to develop 'Smart Specialization'—i.e., taking a system-based approach to the development of distinct regional comparative advantages that work together towards European innovation competitiveness (European Commission, 2022). Likewise, in the United Kingdom, the GBP100 million was awarded in March 2023 to an Innovation Accelerators program aimed at accelerating the growth of "high-potential innovation clusters" in hopes that these mid-sized city regions will become globally competitive, and relying upon significant partnership between local government, business and R&D institutions – an approach that implicitly relies upon stakeholder participation well-beyond more traditional R&D spending.[4]

At the U.S. Federal level, the share of innovation investments including a regional component has also been growing. Table 1 offers a stylized timeline of the rapid growth of Federal place-based innovation policy over the past 15 years, and the rise of similar programs in

[4] Two of the authors (Murray and Stern) are co-founders and directors of a specific educational program supporting these efforts, the MIT Regional Entrepreneurship Acceleration Program (REAP), which has now worked with more than 80 regions around the world across 30 countries in the design and implementation of these types of initiatives (MIT, 2022).

peer nations such as Canada, Australia, the United Kingdom and the European Union. This history reinforces the broad finding of a review of place-based innovation policy by the Congressional Research Service, "The recent expansion of federal support for [regional innovation system] policies may expand the nation's innovation capacity by helping regional economies address barriers to entrepreneurship and the development and commercialization of certain technology areas. As such, the effective implementation of regional innovation systems and strategies will likely remain an area of congressional interest for the foreseeable future." (Lawhorn et al., 2023; see also Roberts-Chapman, 2022).

Building particularly on the 2009 Obama administration's innovation strategy (Executive Office of the President, 2009), Federal departments such as the National Science Foundation, the National Institutes of Health, the Small Business Administration, the Department of Commerce, and the Department of Energy have all engaged in regional investments in innovation. Flagship programs such as the EDA's i6 Challenge, which provides $33 million in regional investments to translate science into technological applications, and DOE's Energy Program for Innovation Clusters (EPIC), with direct financial support for incubators and accelerators developing energy innovations, are but a few examples. Additionally, Federal agencies have incorporated regional inclusion in the criteria used to assess investments more generally. For example, Historically Underutilized Business Zones (HUB Zone) are a focus of the SBA's Small Business Innovation Research (SBIR) grants, and the NIH's Institutional Development Award (IdeA) is a congressionally mandated program that builds research capacity in states that historically have had low levels of NIH funding. With the introduction of the Biden administration's CHIPS and Science Act, the Federal government is also now engaging in several larger and more direct place-based innovation programs, such as the NSF's Regional Innovation Engines (RIE) program, and EDA's Regional Technology and Innovation Hub program. These programs represent a direct expansion of Federal innovation on place-based policies, but also are distinctively different in some key dimensions.

Previous efforts in this area largely supported individual research projects and directed technological development. In contrast, today's Federal place-based innovation programs have a distinctly more ecosystem-based approach. Prior initiatives such as the EDA's i6 Challenge focused on supporting specific technologies and their development, and simply hoped that this development would come with eventual economic spillovers. In contrast, the new programs target a more thorough and systematic approach to partnerships and engagement with local stakeholders in developing a regional innovation ecosystem. Emblematic is the NSF's recently founded Directorate on Technology, Innovation and Partnerships, the first new NSF directorate in thirty years, and particularly its Regional Innovation Engines (RIE) program, which is investing $1.6 billion over ten years. As stated by NSF Assistant Director Erwin Gianchandani, these new initiatives work to "[bring] together not just academia but academia and industry and local community" (Mello-Klein, 2023). Critically, this new stakeholder-based approach to innovation policy necessitates a change in focus from traditional frameworks for regional innovation policy –engaging a much wider variety of local actors and enabling them to be part of the regional development process.

However, despite their increasing popularity of an "Engines" approach, the economic 'logic' of this type of regional innovation investment approach has often been implicit. How are the elements of a place-based innovation policy such as an Engine initiative distinct from traditional regional investments? How do these elements come together to create a new logic for both economic activity and broader regional change? And how does this interaction alter the opportunities for assessment and impact evaluation for innovation financing? These are the questions to which we now turn.

3. The Logic Model

Perhaps the most foundational insight underlying the Engines model is that there is no 'one' agency or actor that oversees a regional innovation ecosystem. Rather, effective place-based policies involve bringing together both public and private stakeholders, including universities, corporations, government, risk capital, and of course, innovators and entrepreneurs. In other words, while economic spillovers have traditionally been understood as a by-product of targeted innovation activities focused on directed invention (e.g., Roberts, 1991), stakeholder-oriented programs focus on creating and potentiating these spillovers as their main goal. Similarly, whereas the use of research in economic activities such as entrepreneurship, workforce development, and technological development has been typically considered a secondary by-product of Federal research investments, today's place-based policies desire to measure their success precisely by whether they are able to achieve such translation and wider use of research as a foundation for innovation and entrepreneurship directly. Rather than investing in advancing research with a vague hope that eventually some of the resulting discoveries may be used, these new place-based innovation policies are directly investing in becoming the 'Engine' of regional innovation for a given location: the motor that in turn enables the acceleration and evolution of all other pieces in the location.

To realize this desired outcome, it is important to first articulate the underlying "logic" model of why and how the program might be effective and why and how it is distinct from more traditional research investments (see Table 2). By and large, the bulk of publicly funded research by Federal agencies such as the National Science Foundation (NSF) has been allocated to individual researchers (or research groups) based on criteria such as (in the NSF's case) "Intellectual Merit" and "Broader Impacts," as judged by expert external reviewers (National Science Foundation, 2018). While such extramural research funding models come with their own challenges (Li, 2017; Azoulay, et al, 2019), the allocation of specific research grants to individual researchers or teams allows funding agencies to connect the funding they provide to identifiable outputs (primarily scientific papers, but also patents, prototypes, and software) that can then be incorporated into subsequent assessments. Most importantly, the traditional model of extramural research funding has been premised on the logic that assessing the underlying scientific quality of individual research proposals on a one-by-one basis has the highest potential for encouraging the submission and support of research proposals and discoveries that ultimately yield the broadest economic and social impact. In other words, while the potential for societal impact is accounted for as part of the assessment process at a holistic level, traditional extramural research assessment need not (and does not) directly trace out the pathway for a specific economic or social benefit that emerges from a single funded grant (much less whether that benefit might or might not be concentrated in the region or country in which the research is conducted).

A regional innovation engine (RIE), in contrast, is premised on a quite different "logic." Relative to a traditional grant, the effectiveness of the RIE program by its very nature depends on inducing changes in the behavior and choices of individuals within a *given* innovation ecosystem (National Science Foundation, 2022). An RIE grant funds activities that are intended to encourage (at least some) researchers to pursue different types of research, engage different (geographically proximate) players in that research, and amplify and accelerate the translation of that research into commercial products and services with regional stakeholders. In contrast to funding whose primary objective is the direct production of high-quality science and engineering research, an RIE is intended to "re-wire" innovation ecosystem connections so that the research being conducted in that location can be leveraged as a driver of high-impact regional innovation and entrepreneurship. Put another way, as a "research-enhancing" intervention, an RIE has the potential to increase the return on investment of more traditional Federal and state research investments, as well as private and philanthropic investments, within a given region.

To be clear, the fact that the impact of an RIE is "indirect" through changing behavior does not in any way imply that it is of low potential consequence. The productivity of research within a given innovation ecosystems depends not on whether research is funded *per se* but on the quality of resulting discoveries, and importantly whether any given discovery can be built on by follow-on researchers or potential commercialization partners in a way that ultimately impacts overall economic growth (Romer, 1990; Mokyr, 2002). As such, the case for the value of the RIE program depends critically on the efficacy by which tailored regional interventions shape not simply the research activities of individual researchers but also the productivity and impact of the entire regional innovation ecosystem. Indeed, in this regard, RIE interventions are more similar to the high-impact investments in research infrastructure such as Biological Resource Centers (BREs) or other repositories (Furman and Stern 2011; Murray et al. 2014) but have a more explicitly regional, and more multi-stakeholder imperative. As such, the most productive RIE investments would presumably be grants that themselves increase the efficiency of current and future regional research investments.

Jones and Summers (2022) offer an instructive method for assessing the potential impact of this approach. They consider the impact of overall R&D investment (both public and private) on cumulative economic growth, and conclude that "even under very conservative assumptions, it is difficult to find an average return below $4 per $1 spent" (Jones and Summers, 2022). Of course, this assessment concerns the average value of R&D overall and does not speak directly to the impact of any specific program such as an RIE. However, since the purpose of the RIE is to enhance the ultimate return from overall R&D investment, the return on the RIE can be calculated in terms of its impact on the average return on R&D investment *itself*. Specifically, if investments in an RIE raise the long-term productivity of the overall R&D conducted in a particular region (even by a modest amount), this creates a highly leveraged impact as a relatively small investment in the RIE has the potential to induce an overall shift in the returns to research across an entire innovation ecosystem.   For example, if a regional university system has current R&D expenditures of $500 million (implying $2 billion in expected net economic value), then an RIE intervention of $16 million per year which results in a 10% increase in the overall impact of that budget (i.e., going from $2.0 to 2.2 billion) implies a more than 10X return on the RIE. Put another way, because the average returns to R&D are so high, if RIEs can increase those returns in a modest but meaningful way, the impact of RIEs (relative to more traditional R&D grants) may be unusually high.

Of course, high potential economic returns from an RIE are not guaranteed. Where and how to target RIE support in a way that can increase the returns to R&D is itself quite a complicated project. Moreover, even if RIE support is successful in increasing the returns to R&D, this by itself does not ensure that any given RIE will generate a significant benefit to the regional innovation ecosystem in which it is based. As emphasized by Lerner (2009), many placed-based efforts to stimulate innovation and entrepreneurship have yielded programs with essentially zero impact on the region they were funded to accelerate. As such, effective design (and also the selection and assessment) of an RIE depends on understanding how the introduction of an RIE is likely to impact the innovation ecosystem in which it is located. For example, consider an RIE whose principal "intervention" is the integration of multiple technology licensing offices across different universities within a region into a "one-stop shop" to support more effective technology transfer. The "logic" for this RIE depends on having a well-grounded hypothesis that this intervention will either (a) increase the disclosure of commercially relevant research by many university researchers, (b) increase the interest in university-based technology by companies and start-ups or (c) increase the likelihood of successful licensing arrangements conditional on the disclosures by researchers and interests of potential commercial partners. However, each of these potential "outcomes" (increased disclosure, increased interest, and increased deals) is not directly under the control of the RIE itself. Instead, the success of the RIE depends on changing the behavior (over time) of researchers, private companies, the process by which researchers and companies interact in the technology licensing process or a combination of these outcomes.

Achieving such behavior change among *regional* companies and start-ups in particular – as opposed to commercial partners more generally – is an even higher bar.

Put another way, as leveraged but indirect investments in regional innovation ecosystems, it is critical that RIEs are selected and implemented in a way that maximizes the potential to enhance the productivity of that ecosystem (even if only by a modest amount). Thus, within a given innovation ecosystem, the first step towards enhancing the productivity of that ecosystem is to diagnose existing strengths and weaknesses and identify how elements of that ecosystem might be re-organized or re-wired in a way that would enhance that specific ecosystem. As highlighted in Figure 1, this specificity is at the core of the "logic" of the Engines model – identification of latent strengths and bottlenecks provide an opportunity to undertake targeted strategic interventions (which will in the near term produce strategy-specific outcomes), the impact of which over time will be to improve broader ecosystem performance (potentially captured by broader ecosystem metrics).

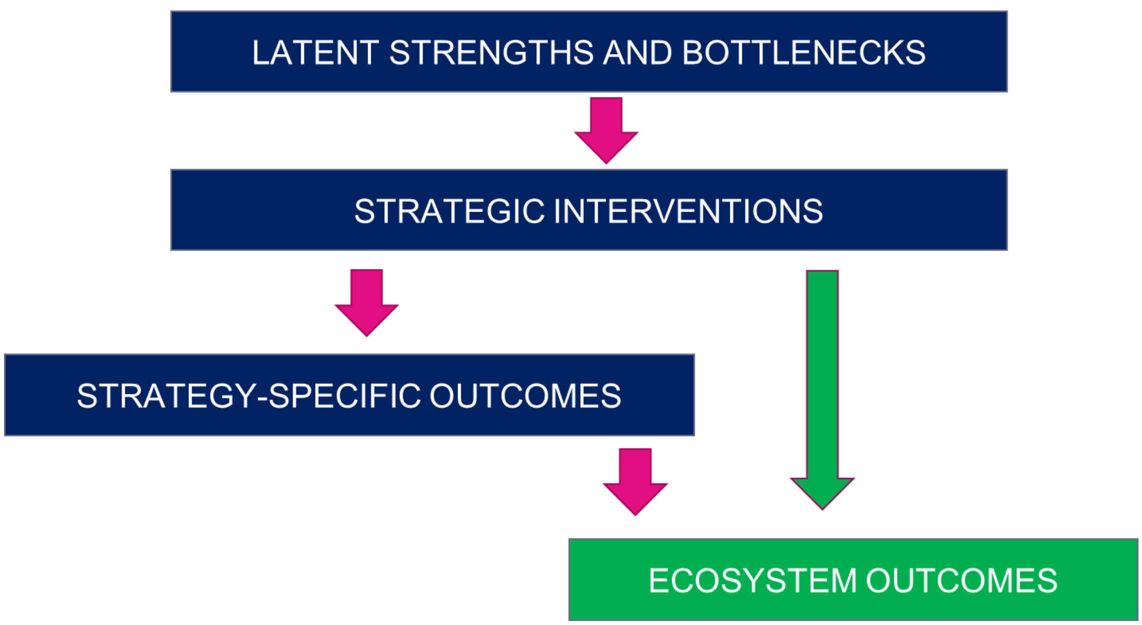

Figure 1: The Innovation Ecosystems Logic Model

A straightforward but important implication of this model is that the precise configuration of resources and capabilities, and the ways in which a regional ecosystem is organized, will differ across any two ecosystems. To be concrete, consider two example regions. Region A is home to a host of strong research universities (producing high-quality research) but lacks a sufficient supply of experienced entrepreneurs who can undertake the entrepreneurial experimentation and learning cycles required to assess commercialization potential. Region B, by comparison, has similarly strong universities (producing the same flow of high-quality research) but also has a relatively strong supply of experienced entrepreneurs. However, in Region B, there are specific barriers in bringing university research and entrepreneurs together in productive ways. Though these two systems would appear similar on important observables (both feature strong universities and lower than expected commercialization outcomes), the challenges and potential opportunities for improved system-level performance in each region are distinct. In Region A, the most valuable intervention to enhance commercialization of university research likely focuses on encouraging potential founders and providing training and mentoring for first-time founders to bring university research from lab to market. In contrast, that intervention would be of much lower value in Region B, which would benefit instead from removing whatever institutional bottlenecks or frictions are limiting technology transfer in an environment which already has an adequate supply of both researchers and entrepreneurs.

Though straightforward, it is worth clearly stating two important observations about this example. First, because the existing states of the ecosystems in Region A and B are different, an intervention that might be of meaningful value in Region A would be of little to zero value in B (and vice versa). In Region B, a training and mentoring program for first-time entrepreneurs may be of little benefit in the absence of the elimination of the technology transfer friction, while removing barriers to technology transfer in Region A may have little return absent a ready supply of would-be and well-trained entrepreneurs. These differences in potential returns (with positive impact from one intervention but zero from the other, depending on the match between ecosystem and intervention) are particularly important given that the overall value of RIEs depends on their ability to play a meaningful (even if modest) role as a leveraged intervention. Second, not only would the nature of the appropriate interventions in each ecosystem be different, but the institutions and “stakeholders” that would need to be involved in implementing and steering that intervention would also be different. In the case of a training program in Region A, the intervention might be housed within a university or in the private sector (or even in a local economic development agency), but would require engagement and active commitment both from the individual would-be entrepreneurs who would participate in the program as well as from the organizations and institutions that could provide the training and mentoring services to remedy the lack of entrepreneurial experience in the region. In the case of Region B, the university would need to work with local entrepreneurs and corporations to identify the institutional or historical reasons for the technology transfer friction, and undertake commitments to remove those bottlenecks in order to achieve a more effective flow of university research into local companies.

At one level this “logic” is straightforward. RIEs are introduced into regional ecosystems that are different from one another, and this heterogeneity in ecosystems induces significant variation in the potential impact of different potential ecosystem interventions. However, the potential importance of tailoring each RIE to the specific opportunities (and challenges) of each ecosystem, and of ensuring that strategic interventions are pursued by the specific institutions and stakeholders that are able to implement the selected intervention effectively, has important consequences for the selection, implementation, and assessment of RIEs themselves. Moreover, it is also worth noting that in each case, the inspiration for the type of intervention and the ecosystem to copy or learn from will be different, reminding us that the current emphasis on becoming the “next Silicon Valley” is misplaced and fails to account for the need for an ecosystem-intervention match. Instead, interventions must be designed carefully through a number of different stages.

First, before choosing how to intervene in a given ecosystem, it is critical to identify the potential “latent” strengths or bottlenecks to the process of innovation and commercialization within that specific ecosystem. While this can be accomplished in a number of ways (which we discuss in more detail in the next section), it is useful to recognize that different agents within each ecosystem (as well as external reviewers who might be assessing the potential for investing in a particular candidate RIE) might disagree on the underlying diagnosis of the as-is system of the ecosystem. These differences might arise from differences in perspective about current capabilities or the salience of particular bottlenecks, but could also arise from differences in the incentives that particular institutions or agents might face. For example, it is possible that a potential bottleneck is the result of the strategic position held by a particular gatekeeper, who would likely argue that their advantaged role is essential (or at least not causing harm). Alternatively, organizations or institutions that might provide the services for particular interventions (e.g., a training program) are likely to argue and provide evidence for the lack of current training within that region.

Second, assume for a moment that it is possible to obtain an accurate, unbiased diagnosis of the current state of the innovation ecosystem. The RIE must then select and prioritize an intervention (or closely coupled set of interventions) that is likely to alleviate the identified bottleneck or leverage a previously under-tapped latent regional capability. While it is possible that a given ecosystem might be able over time to benefit from multiple interventions (to address different challenges and opportunities), the logic model underlying a RIE suggests that interventions should be prioritized based on their assessed potential to impact a given ecosystem.

Finally, given that each intervention is tailored to the distinct opportunities and challenges of each region (that is, both the diagnostic assessment as well as the interventions will be idiosyncratic to a given region), assessing the impact of RIE investments as a category of intervention (at least over the medium term) necessitates the development of metrics and assessment approaches that measure the impact of the specific strategic intervention in the particular region that was undertaken relative to a reasonable counterfactual for how the region would have otherwise evolved. In other words, by the very logic of an RIE being designed to have a unique ecosystem-intervention match, each RIE is likely to have a distinct set of metrics and outcomes that would indicate its progress (and also allow for real-time course-corrections if possible).

This model provides a clear underlying logic about how and why an RIE might have the potential to have a leveraged and disproportionate impact on accelerating regional innovation ecosystems in the United States. On the one hand, the model highlights the importance of linking the diagnoses of the underlying system and the engagement by stakeholders within that system to choose and effectively implement a strategy that can induce behavioral and institutional changes with high potential impact. At the same time, the model highlights the (complicated) assumption that regional stakeholders (i.e., actors and institutions existing within the region) can undertake an accurate and holistic assessment of the regional ecosystem, and propose and then implement RIE interventions that have the ability to change that system in a productive manner. For that assumption and, in turn, the RIE "theory of change" to hold, it is important to understand the interplay between regional stakeholders, ecosystem assessment, and the choice and implementation of key strategic RIE interventions.

4. The Theory of Change

The previous section lays out the underlying logic of an Engine: modest but real improvements in the conditions supporting a regional innovation ecosystem (particularly ecosystems outside the "top" tier of current performance) have the potential to leverage the large average return to existing R&D expenditures and thus offer an outsized impact in terms of social returns. However, in order to realize this potential return, the Engine must target an intervention that removes a key bottleneck, leverages a latent capability, or introduces new capacity to address an economically significant weakness in the current state of the regional innovation ecosystem. By undertaking a strategic intervention that "re-wires" a regional ecosystem, an Engine can potentially induce changes in behavior and action on the part of key actors and institutions within that ecosystem.

Though this logic is straightforward, effective implementation is not. In particular, in order to realize the change in an ecosystem that would allow an Engine to succeed, an RIE must overcome three distinct and interrelated set of challenges: stakeholder engagement, holistic ecosystem assessment, and implementable strategic choice (Figure 2). Before digging into each of these challenges in depth, it is useful to highlight why overcoming all three are *necessary* conditions for realizing the potential returns from an Engine. First, regardless of the quality of ecosystem assessment or the potential value of a particular strategic intervention, the very nature of an Engine requires local stakeholders – usually some combination of universities, government, corporates, start-ups and investors – to engage with the programs and activities of that Engine. Without engaged stakeholders who can facilitate the behavioral changes underlying an Engine, the Engine itself will not succeed. By that same token, stakeholder engagement by itself is not sufficient. The logic model for an Engine is premised on the assumption that these stakeholders are able to undertake an informed and holistic assessment of that ecosystem in order to identify opportunities for high leverage interventions (that will result in enhanced innovative productivity). As such, beyond simply gaining the engagement and commitment of stakeholders, an effective Engine necessarily depends on an assessment process that correctly diagnoses what the key bottlenecks are and lays the groundwork for correctly identifying promising potential investments to address them. Even if stakeholders are engaged and a promising set of investments is identified, realizing the potential of an Engine depends on effective strategic choice and implementation. Any assessment of an ecosystem is likely to identify multiple potential opportunities and narrowing that set to choices that are simultaneously feasible (within a given budget, and over a given time frame) and yet also genuinely high potential is itself difficult. Since each ecosystem is different, selecting high-potential yet feasible opportunities within a given ecosystem requires effective strategic judgment by stakeholders within that ecosystem. And, finally, even if motivated and engaged stakeholders undertake a holistic assessment and identify promising Engine interventions, the success of the Engine itself depends on effective implementation. That requires a timely and smooth operational launch of the Engine, effective day-to-day operations and management, and ongoing incorporation of both qualitative and quantitative feedback and learning to allow for real-time course-correction.

Figure 2: Necessary conditions for Realizing the Potential of an Engine Intervention

The success of an Engine, therefore, hinges on overcoming these three interrelated challenges - Stakeholders, System, and Strategy. Identifying the tools and approaches that enable regional stakeholders to tackle these challenges is a useful and critical step towards the effective design and implementation of an Engines program. However, to understand why these tools and approaches might be effective (and under what circumstances change may be more likely or not), it is first important to understand why each of these challenges individually have often been difficult to surmount. Understanding the nature of each individual challenge makes it possible to identify whether the necessary pre-conditions are in place for an effective Engine.

Stakeholders: No One Is In Charge of Innovation

A distinctive feature of the Engines approach is its focus on enhancing research productivity at the ecosystem level. Rather than focusing on the research or innovation outputs of an individual researcher, an Engine aims to allow researchers and others to ultimately amplify and accelerate the translation of that research into commercial products and services. Each of the individual researchers and innovators who might be impacted by an Engine will, almost by construction, have a primary affiliation (either as an employee, founder, or investor) in a separate organization within that ecosystem. Indeed, it is the ability of the Engine to bring individuals and ideas together in new ways that allow them to potentially accelerate innovative productivity at the ecosystem level.

Consider, for example, an Engine whose objective is to facilitate translational research from local university research to start-ups and companies in a regional industrial cluster. To do so, the Engine might invest in research infrastructure such as a testing lab suited to industrial applications of the research area. The argument for this Engine would be that shared use of the facility by academics, corporate researchers and start-ups would simultaneously lower the basic and applied research costs of all researchers (by allowing them to share the use of the facility), allow for richer interchange of ideas and knowledge in this particular area, and potentially spark direct research collaborations and technology transfer from more academic research to industrial application and scale-up. Relative to a more traditional research grant, the impact of this Engine depends not simply on the effective installation and operation of the testing facility itself but also on whether researchers from different parts of the ecosystem actually utilize the facility in a way that enabled the objectives of this Engine.

The challenge inherent in effectively implementing such an intervention arises from the information, incentives and constraints shaping whether the relevant participants will choose to meaningfully engage. First, simply establishing an Engine does not necessarily imply that researchers and innovators within an ecosystem will be aware of its existence or, more subtly, aware of how the Engine could enhance their own research and innovation activities. Figuring out whether the programs, training, or activities of an Engine might be worthwhile to advance the research, commercialization, or career of a given individual itself takes time and effort. This informational challenge will be particularly salient at the outset of an Engine, since there will not yet be a "track record" that would allow researchers to learn how they might utilize and leverage the Engine in their own activities. Second, even if a researcher is aware of an Engine, the incentives for an individual researcher to participate may be inadequate to induce their participation. As an individual researcher (or research team) considers whether to participate in the Engine they will not (fully) take into account the value of their participation in the Engine on the research productivity of others. This straightforward participation externality will likely lead to a lower level of engagement with the Engine than one that would maximize ecosystem-wide impact. Of course, if many innovators are already engaging with an Engine, then the value of engaging with that Engine will be higher to an additional prospective participant; however, the initial choice to engage with the Engine in the first place (particularly at the outset) will not take into account the impact of engagement on enhancing the incentives of others to participate over time. Finally, even if potential participants are aware of and have sufficient individual incentives to engage with the Engine, effective engagement depends on the ease and transaction costs of involvement. Their ability to participate will depend on rules and governance that would enable the individual researcher to take advantage of the programs, infrastructure, or training that the Engine might provide. For example, if the Engine is focused on providing entrepreneurial education, the ability of university researchers to participate would depend on how that arrangement linked to their university role (which may prohibit outside educational activities). Similarly, in the earlier example of a translational research infrastructure Engine, the ability of individual researchers to use the Engine also depends on whether the Engine and the organizations that the individual work for have established effective rules (e.g., intellectual property ownership) and governance (e.g., management of potential conflicts of interest).

While these three barriers – information, incentives, and institutional constraints – are complex (merit their own in-depth analysis), their impact (in isolation or tandem) is that simply establishing an Engine in no way ensures its success. Most notably, the Engine by itself cannot directly put in place the channels of information, the incentives, or the low transaction costs that enable the participation of a critical mass of individuals across different organizations.

Simply put, *no one is in charge of innovation.* Engines that potentially shape the productivity of the ecosystem are, by definition, interventions that influence individual researchers and innovators by occurring at the interface between existing institutions and organizations. But no one organization, and certainly not the Engine itself, can require individuals across the ecosystem to engage in a way that facilitates the changes in behavior the intervention seeks to induce. At the same time, the individuals conducting research, commercializing innovation, and building start-ups will have as their goal the advancement of their individual projects and organizations, and are neither directly responsible for nor have authority over the productivity of the ecosystem itself.

It is of course possible that, despite these challenges, the choice and implementation of an effective Engine can organically attract attention from individual researchers and innovators. For example, Feld (2012) illustrates the central role of individual entrepreneurs, creative bottom-up initiatives, and a supportive (but not leading) role for government and universities in the evolution of the startup community in Boulder, Colorado. Indeed, it is the decentralized nature of distinct but complementary initiatives that together drive the spillovers associated with a higher level of ecosystem performance. With that said, the willingness of individuals linked to different organizations to engage with an Engine will be powerfully shaped by whether those organizations proactively enable such participation.

Leveraged stakeholder organizations – the institutions and organizations whose employees, founders and funders would be impacted by an Engine intervention -- are the central actors that can facilitate effective engagement with the Engine. In particular, while these stakeholders are not directly 'in charge' of innovation (and cannot unilaterally ensure its success), leveraged stakeholders can directly help to overcome the central challenges facing others who might benefit from engaging with the Engine. For example, stakeholder organizations can provide opportunities for the Engine to communicate to their researchers (e.g., at seminars or conferences) as well as offer targeted connections based on an understanding of what researchers or innovators might be particularly able to benefit from the programs and activities of the Engine. Second, while individual researchers do not directly account for the spillovers they might provide to others when choosing whether to engage with an Engine, leveraged stakeholders have a more direct interest in nurturing and encouraging spillovers across researchers (and across institutions). For example, consider an Engine that facilitates research interactions between large local corporate R&D centers and start-ups within a given ecosystem. While an individual researcher at the large corporation will focus only on the impact of engaging with start-ups on their own program (and how that impacts their individual career, as an example), the company itself has an interest in establishing a productive set of relationships with start-ups and developing a reputation as a strong potential partner for scale-up efforts. Finally, while stakeholder organizations are not in charge of innovation, these organizations do have the authority and scope to shape the transaction costs and incentives facing individual researchers choosing whether to engage. Stakeholder organizations can establish the processes governing engagement and utilization of an Engine. For example, if a stakeholder organization such as a local university proactively establishes the rules and contracts governing formal intellectual property (e.g., in the form of a cooperative research agreement), then a faculty member who might engage with that Engine can simply use the standard template rather than bearing the transaction costs of designing an agreement from scratch. This in turn enhances the net gains from participation in the Engine for the researcher. By providing a direct conduit for information about an Engine, by shaping the incentives of researchers to promote spillovers, and by establishing the rules and processes by which individual researchers engage with an Engine, stakeholder organizations have the ability to shape whether an Engine is able to promote the shift in the innovation ecosystem that the Engine is attempting to induce.

The question then arises as to whether (and under what conditions) key stakeholder organizations will themselves be willing to engage and facilitate the success of an Engine. Simply because a stakeholder might be able to help does not imply it will. The willingness of a stakeholder organization to invest time, effort and resources to enable the success of an Engine will depend in large part on whether that Engine advances the objectives and priorities of the stakeholder organization. Each stakeholder organization has its own interests, as well as distinct resources and capabilities. As such, the choices by its leaders, administrators, and managers will depend not solely on whether the Engine has the potential to accelerate the entire innovation ecosystem but on how that impact might benefit the stakeholder organization itself.

Consider again hypothetical Engine designed to facilitate translational research through shared infrastructure that enables potential scale-up experiments. Its success would depend critically on the willingness of the university stakeholder to inform and encourage faculty to leverage the new facility, and to establish smooth agreements on how to share proprietary materials or inventions. The willingness of the university stakeholder to undertake such actions will depend in large part on whether university leadership believes that doing so enhances the research, teaching, or impact mission of the university itself e.g. through enhanced performance of the technology licensing office (as measured by executed licenses or revenue over time). However, achieving that objective depends not only on the willingness of the university to engage with the Engine but critically on their expectation of the participation of *non-university* researchers and innovators to also engage. In other words, the value of the Engine to that the university stakeholder (and thus the priority they will place on enabling its success) depends on the participation and engagement of *other* stakeholders with that Engine as well as the Engine itself.

Putting these ideas together offers two distinct but interrelated drivers of whether key stakeholders are likely to engage and facilitate a particular Engine: alignment with their objectives, and the degree of engagement by other critical ecosystem stakeholders. In the absence of a clear alignment between the anticipated outcomes of the Engine and one or more key priorities for each stakeholder organization, invest in resources (including scarce staff and management time) or lending of reputation and prestige towards enabling the success of the Engine is unlikely. Moreover, this alignment in general depends not simply on the direct activities of the Engine itself but on the participation of and substantive engagement by other stakeholders within the ecosystem. In that regard, an Engine is a form of platform intervention whose success depends upon attracting the engagement of multiple stakeholders of different types. The fact that the participation incentives of each stakeholder depend on the choices of other stakeholders creates the potential for a coordination challenge; engagement from multiple stakeholders is thus the promise and the challenge of an Engine model.

To understand the nature of this coordination challenge more clearly, it is useful to be more concrete about the distinct stakeholders that operate in a particular ecosystem. Innovation ecosystems, by their nature, are inherently complex, and the specific composition and objectives of these stakeholders will vary, contingent on a region's historical trajectory and institutional arrangements. With that said, five archetypal actors are typically identified within ecosystems in the United States and beyond: universities, regional governments, established corporations, risk capital investors, and startup ventures (Figure 3).

Figure 3: Canonical Innovation Ecosystem Stakeholders

Universities, entrenched in the fabric of the innovation ecosystem, primarily prioritize their tripartite mission of research, education, and service. They serve as pivotal nodes in the knowledge production and dissemination network, boasting a wealth of intellectual capital and a steady flow of skilled human resources. These capacities, however, are often directed towards outcomes that may straddle the boundaries of the regional ecosystem, such as technology transfer and student success, reflecting the inherent tension between their institutional mandate and the geographically bound nature of regional innovation ecosystems.

Regional governments, focused primarily on enhancing regional economic development and addressing pressing social challenges, leverage their unique regulatory and policy-making capabilities to shape the innovation environment. Their engagement in the ecosystem, therefore, is predicated on the potential for local socio-economic impact, aligning with their broader regional remit. When national governments serve as a proxy for regional government engagement in ecosystems, their country-wide remit is at times at odds with their regional ecosystem incentives. Likewise local government may take a narrower view or be subject to coordination across particular towns and cities that together make up a regional innovation ecosystem.

Established corporations, key stakeholders in their own right, seek to harness the innovation ecosystem to bolster their product and service development processes. Their involvement is fundamentally guided by the potential contribution of ecosystem engagement and Engine support to their innovation strategies, which may include absorbing knowledge from regional ecosystems, underscoring their more instrumental approach towards ecosystem engagement. Particularly in geographic regions away from any corporate headquarters (which may be more embedded in the particular geography) corporations are often in ‘selection” mode- picking the places and modes of interaction that serve them best (Budden and Murray 2022).

Risk capital investors, on the other hand, are driven by the prospects of high-return investment opportunities in innovative startups, recognizing the ecosystem's role as a conduit of such opportunities. Their engagement is largely transactional, orientated towards identifying and investing in promising ventures. Startup ventures, the quintessential actors that enable nascent ideas to grow, focus on growing their ventures and translating their ideas into tangible impact. Their engagement with the ecosystem is often instrumental and contingent on their immediate needs, although successful entrepreneurs may subsequently engage in ecosystem-building activities, reciprocating the benefits they initially derived from the ecosystem (Feld 2012).

Consider, for example, a region such as Madrid, Spain, that has strength among individual stakeholders but, through the mid-2010s, had historically struggled to build on those strengths to build a vibrant innovation. Ecosystem.[5] One of the largest metropolitan areas in Europe, Madrid’s economic strength is based on the presence and investment of leading multinational corporations (many of whom use Madrid as a critical linkage between Europe and Latin America) as well as serving as the capital of Spain and so the home of a large government sector. Despite its relative economic prosperity and centrality, Madrid during the early 2010s registered a low level of innovation-driven entrepreneurship (e.g., ranking well behind Barcelona on key innovation ecosystem metrics) and perhaps more importantly failed to leverage the combination of Madrid’s strong university research base, multinational corporate presence, and links to Latin America (Agudo et al, 2018). While the potential gains from leveraging these “latent” strengths might seem obvious (once stated), no particular stakeholder has the authority or resources to create these connections. However, a multi-year “task force” team composed of leaders from all five stakeholder teams was able to identify the specific opportunities and bottlenecks in each of their respective areas to develop and implement a new and Madrid-specific approach. The Madrid Innovation Driven Entrepreneurship (MIDE) network, which engaged in a multi-pronged set of activities to accelerate the Madrid ecosystem through novel stakeholder engagement. For

[5] This example (as well as others throughout this section) draw on individual MIT REAP teams that a subset of the authors have worked with over the past decade. See reap.mit.edu for more details on each of the REAP teams and the particular strategic initiatives they have chosen to pursue.

example, relative to a more "traditional" start-up accelerator, MIDE focuses squarely on start-ups that might benefit from partnerships with leading multinationals, providing a rationale for both multinationals as well as start-ups to become engaged. A complementary initiative focused specifically on identifying opportunities taking advantage of Madrid's link to Latin America, including programs enabling Madrid innovators to access the Latin American market, and reciprocal programs enabling Latin American companies to work with Madrid firms. Each of the distinct "elements" associated with this strategy depended on sustained engagement (and trust) between multiple stakeholders within the Madrid ecosystem, and the rapid scaling of MIDE within that ecosystem reflects the potential for stakeholder-led initiatives to fill a latent "opening" within an ecosystem with the potential for catalytic effect.

While the MIDE example offers a "success" story, it is important to emphasize that the task of identifying strategic interventions that can simultaneously accelerate the ecosystem and align with the interests of these disparate stakeholders presents a significant challenge. A critical aspect of this process is securing stakeholder support and commitment prior to an intervention's launch, which necessitates their inclusion in the intervention's design and a collective vision-building and strategy-making process. This approach underscores the importance of understanding the region's unique strengths, weaknesses, and potential for strategic intervention, which motivates the second element of our overall "Engine" theory of change.

System: Shared Assessment of Regional Innovation Ecosystems

Translating stakeholder collaboration into a strategy is facilitated by the development of a shared assessment of the as-is state of a regional innovation system. Such assessment enables stakeholders to come to agreement on the strengths and weaknesses of their current system, the bottleneck and frictions, and the merits of specific opportunities for change. Assessing the as-is state of a regional innovation ecosystem requires a systematic framework that allows stakeholders to gain a holistic assessment and benchmark metrics for their performance across the full range of activities, resources and capabilities that make up an innovation ecosystem. Figure 4 offers one organizing framework that highlights how region's potential for innovation is shaped by its foundational institutions, its innovative capacity across at least five categories—human capital, funding, infrastructure, culture, and demand—the regional availability for entrepreneurial and corporate commercialization, and a region's comparative advantage.[6]

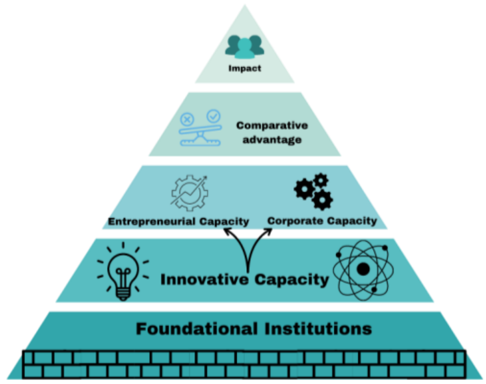

Figure 4: Regional Innovation Ecosystem Performance Drivers

Foundational Institutions. Strong and functional institutions provide the underlying foundation on which innovative work may take place. Robust property rights and a well-functioning rule of law, a developed corporate code that facilitates entrepreneurial investment, ease of doing business and reduces corruption (Lerner and Schoar, 2005; Guzman, 2023), and a well-functioning intellectual property system that protects and incentivizes the invention and diffusion of technology (Kyle, 2007; Cockburn, et al., 2016) are all critical pieces that in combination enable inventors to invest time in innovative activities. Across the globe, variation in these foundational institutions can be substantial. Cockburn et al. (2016), for example, show that differences in the strength of the patent regime across countries lead to a slowing in the adoption of new drugs by almost three times.

Institutions are also important in the more nuanced tuning of the rules and policies that support innovation directly. Non-compete agreements, for example, can represent a key hindrance to the free flow of innovators across firms, reducing economic spillovers (Marx et al, 2009) and entrepreneurship (Starr et al., 2017), yet their presence across the U.S. continues to be substantial

[6] This framework builds on a more targeted framework employed within MIT REAP, which focuses on the potential for innovation-driven entrepreneurship (i.e., the translation of ideas through start-up firms) rather than the more organizationally agnostic approach (where both start-ups and corporates are both potential commercialization channels) highlighted in Figure 4.

(though varied). There is similar variation in the role of local government in supporting the development of strong local universities (Tartari and Stern, 2021), and in creating international relationships with key markets enable trade and idea exchange (Akcigit et al, 2018; Wang, 2015). Recognizing the strengths, shortcomings, and opportunities in these foundational institutions represents a core component of an effective understanding of any innovation system.

Regional Innovative Capacity.[7] While foundational institutions enable a region's innovative capacity, innovative capacity directly depends on several distinct elements within the local ecosystem (Furman, Porter and Stern, 2002). Human capital, representing both the availability of talented innovators to carry out an invention and the presence of additional complementary technologists to scale it from the laboratory into a product, is perhaps the most commonly appreciated input to innovation. Labor is a key input to several innovation-based endogenous growth models (Romer, 1990; Jones, 1995) and is at the core of theories of economic agglomeration (Marshall, 1920). Empirically, increases in the supply of college-educated workers predict future increases in regional productivity (Moretti, 2004; Iranzo and Peri, 2009), and, in immigration studies, regions that receive more STEM-focused immigrants increase patenting per capita (Hunt and Gauthier-Loiselle, 2010; Kerr and Lincoln, 2010). Furthermore, historically, the development of regional ecosystems has also depended on the agency of individual leaders driving and effectuating this change (Feldman, 2001; Feldman and Francis, 2003). Taken together, this type of evidence suggests the presence of talented human capital in a region is critical to achieving high levels of innovation.

The role of financial capital also appears to be quite important. Innovation often requires large investments, and innovators (with a few famous billionaire innovators) are rarely the ones holding the capital needed to develop their technologies. At the earliest stages, the funding of technology often takes the form of government research grants and other procurement policies that support the development of new technologies. An additional significant share is covered through private philanthropy (Murray, 2013). While the vast majority of research grants are provided at the Federal level, other types of policies have a more local component. Examples

---

[7] The term "innovative capacity" has a long history in research in economics, innovation, and geography, including Pavitt (1980), Suarez-Villa (1990, 1993), Porter (1990), and, in the current context, the definition and framework introduced in Furman, Porter and Stern (2002) and the references therein.

include state-level R&D tax credits (Bloom et al. 2002; Bloom et al. 2019; Fazio et al, 2020; Balsmeier et al, 2021), and matching funds which multiply investments from Federal grants (Myers and Lanahan, 2022; Lanahan and Feldman, 2015).

Government and philanthropic research grants are well structured for earlier stage technological development without clear economic applications. Yet, as the technology increases its readiness level, the main driver of development becomes the market opportunity of the technologies themselves (Aghion, Dewatripont, and Stein, 2008). When innovators lack the financial resources to develop their technology, they seek out risk-capital investors that join as equity partners in the formation of a new venture to commercialize this technology (Gompers and Lerner, 2001; Kaplan and Lerner, 2010). These risk capital investors differentiate into two broad groups: Angel investors (Kerr, Lerner, and Schoar, 2014) are high-net-worth individuals who invest their money directly into companies and support their evolution. Venture capitalists, in contrast, are institutional investors that obtain financial resources from institutions and translate capital seeking high growth rates and long maturity into active company investments (Gompers and Lerner, 2001). Venture capitalists tend to be able to invest larger amounts and do so over longer periods of time, but typically invest at a slightly later stage of technological development. In recent years, venture capital models have increasingly been adapted to the mission orientation of particular investors seeking to support innovators solving critical global challenges.

Finally, for inventions that are still not ready to transition into commercialization, the Federal government provides a family of programs such as the Small Business Innovation Research (SBIR) grants (Lanahan and Feldman, 2015), which are aimed at helping technologies that need an additional proof of concept before reaching a stage where they are likely to attract attention from angel and VC investors. The benefits of this financing on innovation appear significant: Howell (2017) shows that receiving an SBIR award almost doubles the probability of a firm filing a patent, and significantly improves financing and employment growth. Bringing it together, the importance of financial capital in enabling the success of regional innovation ecosystems, including the role of philanthropy, government, and risk capital investment, is substantial.

A third area of innovative capacity considers the role of localized infrastructure in supporting innovative work at different stages. The process of knowledge spillovers is enabled by face-to-face interaction (Davis and Dingel, 2019), and knowledge travels locally (Kerr and Kominers, 2015; Arzaghi and Henderson, 2008; Catalini, 2018). This proximity is not only about physical distance, but rather the perceived distance to make ideas 'travel'. The availability of roads, for example, has a significant role in enabling knowledge flows in a region (Agrawal et al., 2017), likewise the introduction of flights between regions (Bernstein, Giroud, and Townsend, 2016). But beyond transportation, infrastructure also considers the institutions available to access knowledge, whether physically or digitally. In the late 20th century, the opening of USPTO patent libraries led to an up to 20 percent increase in regional innovation (Furman, Nagler, and Watzinger, 2021). Assessments of the impact of the Internet on scientific collaboration and innovative output report similar large effects (Agrawal and Goldfarb, 2008; Wernsdorf, Nagler, and Watzinger, 2022).

Infrastructure is also important to enable innovative work directly. Maker spaces, biological wet labs, and shared co-working spaces, all play a key role in reducing the cost of innovation-driven experimentation allowing innovators to pursue more novel ideas (Kerr, Nanda, Rhodes-Kropf, 2014). Accelerators provide key infrastructure to nurture and develop young startup ideas into full-fledge companies with financial capital (Fehder and Hochberg, 2014). And the existence of local bars, restaurants, and coffee shops creates 'third spaces' where innovators can socialize informally and share ideas with one another (Andrews, 2022).

A fourth key domain supporting innovation capacity is a region's culture and incentives. Developing innovation represents a long-term, risky investment into the future. This necessitates broad-based cultural elements such as trust (Guiso, Sapienza, and Zingales, 2009), a preference for change and entrepreneurship (Chinitz, 1961; Glaeser et al, 2015), and a culture of innovation and rule-breaking (Senor and Signer, 2009). In her seminal comparison of Silicon Valley and Route 128, Saxenian (1996) emphasized differences in culture, including Massachusetts's long history of Puritan values, as one of the key components that both led to the divergence of the innovative output between regions, and shaped the way innovation was done for incumbents in each. Similarly, analyses of the Israeli innovation ecosystem and its success tend to place Israel's unique culture, characterized by innovativeness but also a willingness to break the rules and low acceptance of authority, as one of the main elements enabling Israel's success (Senor and Singer, 2009). Each location, however, is also distinctively different. As emphasized by Feldman (2014), successful innovation clusters have a "character of place—a spirit of authenticity, engagement, and common purpose" that underlies the regional interactions of innovation-oriented stakeholders.

The role of culture and incentives is even more relevant because it shapes the regional supply of human capital through migration. A key insight in the classic work of Borjas (1987) is that regions that reward high skill (including innovative skill) attract more skilled individuals, particularly at the high end of the distribution (also Kerr, 2020; Bloom, Van Reenen, and Williams, 2019). This is true also for the quality of living in a location. Florida (2004) proposed that highly livable locations that incorporate culturally diverse and interesting contexts (such as art and music) make themselves attractive to highly skilled individuals that then also play a key role in local innovation and growth. The important role of quality of living appears to be partially borne out in the patterns of migration of high growth entrepreneurs (Bryan and Guzman, 2023).

Finally, regional innovation depends on the important role of demand. Innovation does not happen in a vacuum. Rather, the goal is to create useful ideas that are demanded by the market. Management scholars have traditionally emphasized the importance of proximity to customers in developing an innovation, particularly in transitioning from an early-stage idea to a product that is scalable (Blank, 2005; Cespedes, Eisenmann, and Blank, 2012). Trade economists have also referred to the 'home market hypothesis'; the idea that local demand for a product predicts exports of such products due to both innovation and learning as well as production costs (Linder, 1961; Krugman, 1980). Costinot et al. (2019) document evidence for the importance of local demand on innovation: across the world, exogenous changes in the demand for local drugs due to changes in potential causes of death predicts increases in innovation and exports in those categories by region. The types of innovations for which there is local demand, not simply international demand, tend to be those that are most successful when developing in a region.

Entrepreneurial and Corporate Capacity. The success of an Engines-based intervention approach will essentially always require effective commercialization through complementary companies, either in the form of entrepreneurship (creating new to the world ventures) or (existing) corporations. These two modes of commercialization are fundamentally distinct. Yet, virtually identical "twin" ideas can often present themselves in either mode based simply on the inventor history and track record, or other seemingly extraneous factors (Marx and Hsu, 2022).

Endogenous growth models emphasize that the more disruptive and innovative ideas tend to be overwhelmingly performed by new entrants (Akcigit and Kerr, 2018; Aghion and Howitt, 1992). The entrepreneurial capacity inherent in the density of new entrants reflects the region's inherent capability to start new companies (particularly those based on their innovations). Even locations with significant education in scientific skills and production of new ideas may fail to translate these into economic impact if the right entrepreneurial capacity is not available to take advantage of them. The ability to link innovation to entrepreneurship depends on specific local institutions such as technology transfer offices, employment contracts, entrepreneurial culture, and the local structure of the complementary services. In many cases, the link from innovation to entrepreneurship occurs as an inventor decides to start their own firm or find a team to do so. However, the incentives for entrepreneurship can play a key role in their choice to do so (Baumol, 1990; Murphy, Shleifer, and Vishny, 1991). Universities vary widely in the way in which they structure the benefits of, and rights to, participate in new ventures based on their inventions, with significant differences in subsequent entrepreneurship. Hvide and Jones (2018), for example, provide compelling evidence that the end of Norway's 'professor's privilege'—where university researchers previously enjoyed full rights over the innovations they created—reduced academic entrepreneurship by 50 percent in the subsequent years. In the same vein, using data from Finland, Aghion et al. (2018) document that while innovators themselves accrue only 8% of the return their inventions, entrepreneurs receive 44%. In short, the role of entrepreneurs in translating innovation into actual firms is significant. The capacity for entrepreneurship is, therefore, a key component of the way innovations become actual market-based products that benefit productivity and create employment growth.

Yet, a substantial share of R&D occurs in large corporations rather than startups. Corporate R&D tends to focus on products for internal use and process improvement (Rosenberg, 1990; Jaffe, 1986; Arora, Belenzon, and Sheer, 2021), and more on the development of products than research per se, a trend that has been increasing (Arora, Belenzon, Patacconi, 2017). Part of this shift from fundamental research is the growth of 'open innovation' (Chesborough, 2003). In this organizational model, corporations allow startups to develop ideas and then collaborate with these startups (through licensing or acquisition) to distribute the technology across the market. In contrast to the typical image of disruptive entrepreneurs displacing incumbents, the majority of successful startup exits are acquisitions to be incorporated into larger companies (Catalini, Guzman, and Stern, 2019; Puri and Zarutskie, 2012; Almazan, 2010). In this way, the role of corporations in enabling innovation encompasses three distinct elements: performing innovation itself, developing others' academic or industry innovations into products, or through the incentive effects of making startup investments in the broader startup ecosystem.

Regional Competitive Advantage. Finally, it is fundamental to consider a region's comparative advantage. While comparative advantage plays an important role in trade models (Ricardo, 1817; Dornbusch et al, 1977), and many innovation policy models focus on developing 'tradeable' industries that participate in the national and international economy (e.g., Porter, 1998; Delgado, Porter, and Stern, 2014; Kerr and Robert-Nicoud, 2020), the implementation of many regional innovation initiatives appear to ignore the central importance of comparative advantage. As emphasized in Lerner (2013), this omission has predictable negative consequences for the success of regional innovation efforts. Rather than developing a unique position in the overall international value network supporting exports of goods or services, regions often invest in the fast-growing industry *du jour* hoping to simply catch the next wave of innovation. Even in cases where regions are attempting to get out of a faltering or antiquated industry it is more promising to focus investments on specific opportunities grounded in a region's location, history, capabilities, cost-structure, and current innovation capacity. This focus allows for new and emerging bets that offer a differentiated value proposition within the global economy.

The process of selecting an appropriate strategic intervention necessitates a comprehensive understanding of the ecosystem's current capabilities and limitations, as well as an awareness of global trends and best practices in the realm of innovation and entrepreneurship. While some regions often have industry specializations, it is more often also the skills on general purpose technologies—such as software development—and the way in which local culture enables a variety of innovative activity, that are the comparative advantage that allows regions to be resilient towards future economic changes in specific market conditions (Kerr and Robert-Nicoud, 2020).

Stakeholders must engage in a collaborative effort to map out the existing resources and networks within the region, while also identifying the key challenges and barriers that hinder innovation and growth. Once an understanding of a region's unique strengths, weaknesses, and potential for strategic intervention is in hand – which, to be clear, is no small undertaking – the groundwork laid for designing an Engines-style intervention.

Strategy: Selecting a Regional Innovation Engine

Through shared assessment of their innovation ecosystem stakeholders will be able to identify what is unique about their regional ecosystem. Of course, simply analyzing that system (even with committed stakeholders) is not sufficient to enable the change that realizes the underlying logic of the Engines model. Instead, stakeholders need to identify a set of strategic interventions (the smaller the better) that align with their underlying objectives and which, they believe, have the potential for "re-wiring" their particular innovation ecosystem.

Given the criticality of this choice, it is useful to consider some of the potential strategic interventions that these stakeholders might consider: commercialization and acceleration programs, human capital and workforce development, innovation partnerships, and investment and risk capital. Each of these interventions has been subject to both academic analysis and practical experimentation. As highlighted in Figure 5, these programs offer a menu of interventions that are most likely to be observed within an Engines-style program.

By carefully selecting targeted strategic interventions based on a detailed assessment of the regional innovation ecosystem and the objectives of the stakeholders involved, it is possible to develop a more focused and effective approach to fostering innovation and entrepreneurship. Such a targeted approach, grounded in empirical evidence and academic research, can help accelerate the growth and development of the ecosystem, promoting economic prosperity and enhancing the region's competitiveness on a global scale. Ultimately, the success of any strategic intervention hinges upon the collaborative efforts and commitment of diverse ecosystem stakeholders, working together to build a more growth-oriented and sustainable future. As such, it is useful to consider the four key domains of intervention that have been found to be particularly valuable in the context of regional innovation ecosystem acceleration. Table 4 offers an overview of these interventions, including the specific rationale for each program, the types of metrics that might be associated with their outcomes, and key references and exemplars of programs of this type within the Federal system.

Figure 5: Regional Innovation Engine Strategic Interventions

Commercialization and Acceleration Programs

Commercialization and acceleration programs are critical strategic interventions designed to support the growth and development of start-up ventures within a regional innovation ecosystem. These programs typically provide a range of resources such as mentorship, networking opportunities, training, and access to funding, which can help businesses accelerate their growth and development. While many are operated by the private sector (with little engagement with other stakeholders), over the last decade such programs have become a mainstay of public support for entrepreneurship and innovation, including public-private partnerships, university accelerators, and narrowly defined industry offerings (Hochberg, 2016; Cohen, et al, 2019). Indeed, over the past decade, the Federal government has sponsored a range of accelerator programs, including the i-Corps program first developed at the National Science Foundation (and then adopted and adapted at other agencies).

The intended benefit of commercialization and acceleration programs is the support and structure they provide startups and early-stage ventures, along with some critical resources they need to succeed early in their startup journey. While the accelerator model was initially pioneered by venture capitalists (most notably the teams that founded Y Combinator and TechStars, respectively), emerging evidence suggests that publicly supported accelerators have the potential to accelerate the growth of the ventures they support. For example, Gonzalez-Uribe and Leatherman (2018) provide evidence that, relative to start-ups that applied for but just missed admission to a public program, Start-Up Chile, whose admitted start-ups experienced higher survival and employment growth, as well as a higher rate of follow-on funding. The positive impact of accelerators using regression discontinuity has been documented across several studies (Fehder, 2023; Gonzalez-Uribe and Reyes, 2021; Howell, 2020).[8]

Furthermore, by fostering collaboration between entrepreneurs, investors, and other ecosystem stakeholders, these programs enable more vibrant and connected regional innovation ecosystems. Fehder and Hochberg (2014) provide suggestive evidence that the introduction of an accelerator into a region that has a low level of venture capital investment not only increases risk capital financing for the firms that participate in the accelerator but also other firms in the region (who might benefit from the new presence of these venture capitalists in the region).

Regions with a solid foundation of early-stage innovation and potential entrepreneurs can greatly benefit from accelerator and commercialization programs. These programs are particularly useful in situations where individual startups may be lacking the necessary experience, networking opportunities, and mentorship to facilitate rapid growth and scaling, in specific stages of the commercialization process. For example, the Creative Destruction Lab (CDL), initially founded in 2012 at the University of Toronto, was designed to provide intensive mentoring, feedback and potential investment in the emerging area of artificial intelligence (AI), an area in which Toronto long had significant research capacity. By providing opportunities for early-stage entrepreneurs to access the judgment and network of more experienced founders and investors, CDL provided a concrete program enabling commercialization in the emerging AI field. Founded in 2012, the CDL model has now expanded to 12 regions around the world (each specialized in a particular area relevant to its innovative comparative advantage), and companies

[8] Yu (2020) uses a matching strategy to report more nuanced results on the role of accelerators, in which (relative to matched startups) accelerators help startups 'fail fast'. Lyons and Zhang (2017) show that accelerators are usually most useful for individuals without much prior startup experience.

that have participated in the program are now valued at more than $20 billion USD (Creative Destruction Lab, 2023).

Human Capital and Workforce Development Programs

Human capital and workforce development programs are strategic interventions aimed at enhancing the skills, knowledge, and expertise of individuals within a regional innovation ecosystem (including attracting new individuals to the region). These programs focus on providing specialized training, education, and professional development opportunities tailored to the innovation ecosystem's specific needs, such as technology (at all stages from early demonstration to engineering and manufacturing), entrepreneurship, and research skills. Such programs may be offered through universities, vocational schools, public or private training institutions, or partnerships between educational institutions and industry stakeholders.

Human capital and workforce development programs aim to address bottlenecks for stakeholders that either require additional talented workforce to improve their ecosystem or provide the skills and ability for innovators and entrepreneurs to translate their innovative work into commercial products. When companies cannot find enough talented people to scale or feel the need to hire outside the local region to find them, when foreign companies do not see the focal region as a promising location for investment and growth, or when local individuals in charge of innovation appear to miss a local understanding of the steps through which one engages in commercialization and entrepreneurship, policymakers may wish to consider that an intervention aimed at human capital and workforce development.

While academic research on workforce development programs has long studied the role of STEM abilities on career outcomes (Freeman, 1979; Deming and Noray, 2020; Stephan, 2012), recent research places a particular emphasis on the importance of training for R&D output. Indeed, a central function of Federal support for innovation are a range of training and support programs for graduate and post-doctoral students, including for example the NSF Graduate Research Fellowships Program. Moreover, training interventions seem to have a significant impact on research careers, productivity and impact. For example, in a study the NIH 'Yellow Berets' program, in which medical school graduates where invited to participate for up to three years in research at the NIH, Azoulay et al. (2021) document an impact of the program in increasing its graduates future R&D. Compared to similar applicants who ultimately did not join the program, Yellow Berets where more likely to choose a research-focused career, train more researchers, and perform better in a range of research productivity publications (including unusually high-impact science garnering accolades such as the Nobel Prize). Other studies also show how relatively short training programs at the earlier stages of an individuals' career impacts their level and direction of scientific involvement (Jacob and Lefgren, 2011; Fry, 2023).

Of course, training programs need to be exclusively focused on innovation but also on more the experiences and programs that result in "entrepreneurial capacity" -- the practical skills associated with founding and scaling innovation-driven start-ups. For example, there is significant evidence that the choice and conditions under which academic researchers become entrepreneurs depends not simply on their research activities but also the social context and networks they have formed within and around their laboratories (Murray, 2004; Ding and Stuart, 2006; Murray, Ding and Stewart, 2008); indeed, when students train in a lab where the principal investigator is more "entrepreneurial," these students do tend to shift towards more commercial activities (Agarwal and Ohyama, 2013; Azoulay, et al, 2013; Roche 2023). While there is substantial evidence that entrepreneurial skills can be "learned" through exposure to others within one's social network, the impact of formal entrepreneurship training programs is somewhat more mixed. In particular, while there seem to be few benefits to purely aspirational programs unconnected to real-world ventures (Astebro and Hoos, 2021; Oosterbeek et al, 2010; Carlson, 2021), programs targeting existing founders seem to have a meaningful impact on firm-level outcomes (Dimitriadis and Koning, 2020; Chatterji et al, 2019). For example, in a recent study, Bailey et al. (2023) undertake a randomized evaluation trial offering entrepreneurial education to more than 500 innovation-driven start-ups across 12 U.S. accelerators (which they are able to compare to a control group that did not receive this training); the authors find that those that participate in the program are able to both "fail faster" (for those whose idea is unlikely to scale) but, conditional on survival, are able to attract significant additional capital.

Human capital and workforce development programs are best suited for regions that have a strong pre-existing innovation system in a particular domain but lack a critical capability that can be addressed through a targeted program.   For example, with funding from both the Massachusetts state government as well as industry, Quincy College in Massachusetts pioneered a biomanufacturing associate degree program in the early 2010s, which leverages donated specialized equipment from leaders in the regional biotechnology cluster to offer practical and timely skill development to enable the operation of regional biomanufacturing plants (Scheible, 2014). In particular, consistent with the "Three S" model described earlier, it is useful to emphasize the effectiveness of this program depends on the willingness of local biotechnology companies to undertake the effort to repurpose their specialized machinery for use by the Quincy College, and investment on the part of Quincy in establishing and maintaining a new academic program (that depends on the implicit promise of continued support by the local industry).

Administratively, a key role for Federal agencies to support the human capital needed to enable the success of Engines-style approaches is to take advantage of administrative flexibilities for these regional hubs to bring in (or allow to stay) high skill immigrants in areas where there would otherwise be key labor shortages. For example, the Bureau of Educational and Cultural Affairs launched the Early Career STEM Research Initiative last year, which will expand opportunities for startups spun off from technology transfer offices and other Engine institutions to host researchers on J-1 visas. NSF can assist in retaining these researchers (some of whom are required to return home when their J-1 expires) by acting as an "Interested Government Agency" and requesting a waiver from the State Department. To give another example, U.S. Citizenship and Immigration Services (USCIS) can clarify when H-1B cap exemptions apply to Engine-affiliated institutions.

Innovation Partnerships

A third type of initiative – innovation partnerships – focuses on the regional acceleration impact that can arise from effective collaboration and resource and capability sharing between different organizations and individuals. Innovation partnerships allow different agents within the innovation process to gain access to specialized knowledge and material, engage in agreements that leverage each organization's comparative advantage, and tap into the resources, knowledge and capabilities that allow a region to extend its comparative advantage. At its core, an innovation partnership is a strategic arrangement where different actors within the innovation process — be it startups, research institutions, established businesses, or individual innovators —

capitalize on their unique strengths through resource sharing, thus promoting access to specialized knowledge, expertise, and facilities.

Innovation partnerships include a range of specific approaches, including structured approaches to technology transfer, the development of shared research and innovation infrastructure, and investment in region-specific cluster initiatives that aim to leverage areas of regional comparative advantage. While each of these types of initiatives is distinct (and a deep dive on each beyond the current scope), they share the feature that their effectiveness arises from enabling the transfer of knowledge and technology across organizational boundaries and therefore allow for more effective development and scaling of innovation.

Moreover, an emerging body of evidence provides support for the potential effectiveness of innovation partnerships in promoting the process of innovation and entrepreneurship. In the domain of technology transfer, early research documented the striking rapid rise of the commercialization of university invention after the passage of the Bayh-Dole Act in 1980 (Jensen and Thursby, 2001; Mowery, et al, 2001), with many other countries adopting a similar model over time. Hausman (2022) provides careful evidence for the impact of this change, demonstrating that the increases in patenting (and employment and entrepreneurship growth) are concentrated in those industries and sectors where a regional had comparative advantage; similarly, Hvide and Jones (2020) document that reducing the ability of university researchers to commercialize their research significantly reduces the rate of commercialization of that research. Another type of innovation partnership comes in the form of shared research infrastructure. A wide range of studies now documents the potential research-enhancing impact of these types of initiatives, including those arising from the sharing of research materials (Furman and Stern, 2011), data (Furman, et al, 2021; Nagaraj and Tranchero, 2023), and specialized research facilities. Finally, a complementary body of evidence highlights the critical role of comparative advantage in the form of clusters, and the impact of a strong cluster environment on subsequent innovation, entrepreneurship, and economic performance (Delgado, Porter, and Stern, 2010; 2014; Chatterji, Glaeser, and Kerr, 2015; Moretti, 2021), and there is a rich (mostly qualitative) literature highlighting the potential for cluster support organizations to enable and extend the logic and strength of regional cluster through specific initiatives.

The value of innovation partnerships is particularly valuable in an environment where there is a pre-existing set of strengths (in the form of individual research organizations (e.g., universities), particular research resources, or areas of comparative advantage) but effective commercialization and scaling is hampered by lack of effective coordination and partnerships among different actors within the ecosystem. Consider the Canadian Ocean Supercluster program in Atlantic Canada exemplifies this targeted approach to economic development and sustainability.[9] The rationale behind this initiative is rooted in the unique geographic, economic, and research strengths of Atlantic Canada, which boasts a rich history and expertise in ocean-related industries. The Ocean Supercluster program leverages these regional advantages to drive innovation, economic growth, and technological advancement in sectors such as shipping, fisheries, offshore resources, and marine renewables. By fostering collaboration among a diverse set of stakeholders including businesses, research institutions, and government entities, the program promotes knowledge exchange, resource sharing, and technology transfer. This collaborative approach not only accelerates the development of innovative solutions to ocean-related challenges but also enhances competitiveness and resilience in the face of global economic changes. The Ocean Supercluster, thus, underscores the power of regional clusters in catalyzing sustainable economic growth and harnessing a region's unique strengths.

Investment and Risk Capital

A final (and distinctive) type of interventions are strategic initiatives that aim to improve the availability and accessibility of financial resources for innovative startups and growth-oriented businesses within a regional innovation ecosystem. These interventions can take various forms, such as venture capital funds (Gompers and Lerner, 2001), angel investor networks (Kerr et al, 2016), public investment programs (Lanahan and Feldman, 2015), hybrid public-private funds and loan guarantee schemes, all of which are designed to provide the necessary capital for the types of high-risk, high-reward ventures that a region is hoping to build.

In essence, investment and risk capital interventions address funding gap(s) that often exist for early-stage ventures that seek to commercialize novel technology. Howell (2017), for example, presents careful and persuasive evidence documenting a meaningful impact of the

[9] https://oceansupercluster.ca/

single largest publicly funded source of innovation capital for start-up firms – the SBIR/STTR program. Looking at firms that are just above and below a threshold of receiving funding through the Department of Energy SBIR/STTR program, Howell documents that those firms that receive a grant are able to achieve a higher level of innovation (as measured through high-quality patents) as well as follow-on financing (e.g., private venture capital). Moreover, recent evidence suggests the receipt of this early-stage SBIR/STTR financing not only benefits the focal firm, but leads to substantial local spillovers to additional local innovation (Myers and Lanahan, 2022). Furthermore, in the case of venture capital financing, the receipt of CV provides a range of additional elements beyond financing that boost the performance of firms in general, such as monitoring (Lerner, 1995; Bernstein et al, 2016) and social networks (Sorenson and Stuart, 2001) with an important impact on aggregate economic performance (Kortum and Lerner, 2001).

Investment and risk capital interventions are particularly well targeted to locations that have appropriate levels of entrepreneurship but lack the financing to grow these companies or where it appears similar companies are able to get financing elsewhere, where there is an absence of 'early stage capital', such as angel investment groups and mentors, or where there is an absence of local outcomes and success such as entrepreneurial IPOs, despite a promising innovation and entrepreneurship pipeline. Challenges in implementing these interventions include attracting experienced investors and fund managers, ensuring that investments align with the needs of the regional ecosystem, and navigating regulatory and legal complexities. When the right opportunities come about, the impact of investment capital on local economic development can be substantial (Samila and Sorenson, 2011).

For example, Singapore had undertaken a large and sustained investment in growing its research and innovation capacity from 2000-2015, but still had only an embryonic level of risk financing. Building on feedback and with support of other stakeholders, the government established a new government department, SG Innovate, whose aim was to identify, nurture and invest in "deep tech" Singapore science-starts. A particularly important initiative of SG Innovate has been the successful establishment Startup SG Equity, which has to date been able to undertake more than $200 million USD in early-stage financing (by and large in partnership with private venture capital (both from Singapore and non-Singaporean investors).

While these thumbnail sketches of these four types of strategic interventions – Commercialization and Acceleration, Human Capital and Workforce Development, Innovation Partnerships, and Investment and Risk Capital – are in no way intended to be a comprehensive assessment of each, the distinct logic and potential impact of these potential interventions underlies the broader promise and challenges of the Engines approach. Specifically, while each of the interventions from this menu may be an effective intervention for one region (since that region needs to overcome a particular bottleneck that the intervention is designed to address), no intervention is likely to be appropriate or the most effective strategic intervention for every region. As emphasized earlier, it is only by undertaking a detailed stakeholder-led assessment of the unique conditions and opportunities within each region that a tailored intervention for each region is likely to be identified and implemented.

5. Choosing and Implementing an Engine

The core insight of the Engines approach is that the careful selection and implementation of targeted strategic interventions based on a thorough assessment of the regional ecosystem may have the potential for an outsized impact in innovation and economic performance. It acknowledges the multifaceted and interconnected nature of innovation ecosystems and allows for tailored strategies that address specific needs, gaps, and opportunities within a region. By focusing on areas such as commercialization and acceleration programs, human capital and workforce development, collaboration, clusters, and tech transfer, and investment and risk capital, stakeholders can create a supportive environment that enables the creation, scaling and development of critical technologies and the extension of regional comparative advantage.

However, consistent with the broad challenge that the Engines approach seeks to address, the effectiveness of the Engines model will depend critically on the choice and effective implementation of any given Engine. Three particular considerations are likely to be particularly important: assembly of the initial stakeholder team, whether the Engine that is chosen accommodates regional and institutional constraints, and effective implementation, including real-time assessment and course correction.

Stakeholder Team Assembly and Engagement

While stakeholders are conceptual groups with specific and differentiated interests and incentives, they are represented by individual people coming together into an Engines team, and it is through their individual interactions that the process of system evaluation and strategy (and implementation) takes place. Of basic importance is the representation of each stakeholder group—universities, corporations, entrepreneurs, capital, and government—within such a team. Including each stakeholder groups guarantees that their varied perspectives are considered in both the system evaluation and the development of strategy and brings important regional understanding and buy-in from the different elements of their innovation ecosystem. The representation of each stakeholder group requires incorporating organizational background, functional expertise, and political capital into the discussion. Effective stakeholders can not only represent a specific group's view, but also effectuate change and support from this group on the ongoing plan. They can speak for, and create commitments for, change, and they bring an in-depth understanding of their ecosystem to provide a clear and high-fidelity assessment.

It is also important to go beyond the stakeholders in a traditional innovation Engine, to consider those from disadvantaged groups whose voices are less frequently heard, particularly in conversations related to high-growth innovation. To the extent that specific interventions impact underrepresented minority groups, lower income segments, individuals with disabilities, or others, it is valuable to include specific representatives of these groups and provide an equal seating at the table. This might include community organizers, labor organizers, or even religious leaders in the community. It is useful to incorporate their perspective on how the program can be adapted to create greater the positive and inclusive impact, as well as have the groups' buy-in and support.

Finally, it is important to consider team dynamics. A critical insight of the innovation literature has been recognizing the importance of regional 'champions' in leading regional innovation initiatives (e.g., Feldman, 2001; Feldman and Francis, 2003; Feldman,2014). Champions are talented individuals that have the agency, vision, and capacity to create changes in an ecosystem where none have existed before. They bring the energy and commitment that binds initiative together. As argued by Feldman (2014) when reflecting specifically on the role of entrepreneurs "Entrepreneurs benefit from location. But entrepreneurs are also pivotal as agents of change that can transform local communities. The initial event or entrepreneurial spark that gives rise to prosperous regions is not deterministic, nor do they automatically set in motion path dependencies that automatically yield successful places." This critical role of a champion, however, can come from any stakeholder group, including government, risk capital, universities, and corporations.

Practical Strategic Engine Choice

The Engines model is grounded on the idea that motivated stakeholders who engage in a "system-level" analysis of their regional ecosystem will be able to surface critical bottlenecks or latent opportunities that have the potential for a leveraged impact on the innovation ecosystem going forward. And, to first approximation, the central criterion for choosing an Engine should be whether the Engine has a meaningful chance for having a catalytic impact on the regional innovation ecosystem. The potential value of an Engines approach arises precisely because the strategy is chosen to specifically fit and enable the region in which the Engine will operate.

However, the assessment of the potential impact of the Engine cannot simply be its "theoretical" potential without regard to specific regional or institutional constraints. The potential effectiveness of an Engine depends on whether it will be able to be effective and impactful in the specific environment in which it will operate. For example, if a regional stakeholder team identifies bottlenecks in the technology transfer process from the university, then a potential intervention such as reforming the technology licensing office is only likely to be effective if there is meaningful buy-in from senior leadership in the university administration and a legal and institutional environment in which such changes are feasible. If existing laws restrict or inhibit the creation of an innovation partnership program, then an Engines intervention (in isolation) is unlikely to be effective (in this case, legal or policy changes would first need to be implemented). As well, the strategies developed through an Engines initiative need to be consistent with the program's constraints in terms of both funding and timeline. The budget for an Engine might vary widely from a few hundred thousand dollars in a year to hundreds of millions of dollars over more than a decade, seeking to develop completely new technology areas or a new way for an ecosystem to work. Naturally, these budgets allow for very different strategies (with the longer budget and time frame allowing for more holistic change while the short-term effort likely only addresses specific concerns or weaknesses).

Implementation through Assessment and Course Correction

Finally, the impact of any given Engine will depend critically on effective implementation. As already suggested, the Engine needs to acquire both the financial and institutional resources required to achieve the chosen objective, and a timeline and authority in order to implement the specific initiatives that have been prioritized. At the outset, it will be critical to attract talented and motivated individuals to lead and manage the Engine, and also situate the Engine (both physically and in terms of organizational governance) in an environment in which it can operate effectively. Different organizational choices will of course have different consequences for the likely impact of the Engine itself. For example, if the Engine is located directly within a university (and subject to university administrative rules), it can benefit from the immediate "legitimacy" it has through its linkage to the university; at the same time, administrative bottlenecks or lack of commitment by the university itself can undermine an initiative even if it addresses a critical bottleneck at the ecosystem level. Analogously, establishing a new organization (e.g., a new non-profit organization) comes with the freedom to design the Engine to be purpose-fit for the intervention, but faces the challenge of gaining traction and legitimacy in the ecosystem (i.e., an independent Engine is itself a "start-up"). Proactively choosing an organizational approach that enables the most critical priorities of the Engine will therefore be important for the effective implementation of the Engines strategy.

Given that each Engine will be choosing a distinctive strategy, and given the challenges of ongoing engagement and implementation, proactive monitoring and gaining real-time feedback will be particularly important. While real-time monitoring cannot (by itself) provide a retrospective assessment of the impact of the Engine, timely measurement and informed ongoing assessment can nonetheless be critical for effective implementation. At the earliest stages of an Engine, many of the metrics will essentially be "process-oriented" (did the Engine recruit its first class of start-ups on the agreed-upon schedule?) of "activity-based" (how many innovators and entrepreneurs have participated in early events and programs?). Over time, real-time monitoring can begin to capture early-stage "surrogate markers" for the potential impact of the program. For example, while achieving timely commercialization milestones does not guarantee the success of a start-up that has participated in an accelerator program, bringing some products to market is a necessary condition for the ultimate impact of the accelerator itself. Not simply informative about the participants, real-time measurements allow the Engine itself to engage in course correction and adaptation. For example, there will often be multiple aspects to a given program (e.g., serving different populations, engaging different stages of the innovation process). Identifying which initiatives are gaining meaningful traction within an ecosystem may allow resources on the margin to be diverted to those efforts that yield higher payoffs and have been revealed to potentially have higher impact within a given ecosystem.

6. Concluding Thoughts

It is useful to conclude by recalling the motivation for our analysis: the disappointing results that have often been associated with regional interventions in innovation and entrepreneurship that aim to activate and nurture local ecosystems (Lerner, 2009). However, these failures are not inherent to the process of innovation and entrepreneurship per se, but are more squarely attributed to the fact that such programs often have languished due to a lack of investment in "setting the table" and enabling complementary investment and commitments from local stakeholders (including risk capital, corporate, government, entrepreneurs, and universities). Our key insight – "no one is in charge of innovation or entrepreneurship" --- simultaneously captures the essential contracting problem that must be overcome (i.e., lack of effective stakeholder coordination and commitment) as well as the potential path towards a potential alternative approach. Specifically, our approach puts at center stage the interplay between meaningful stakeholder engagement, systematic assessment and tailored strategic interventions that aim to address regional bottlenecks or target latent and distinctive regional opportunities.

It is useful to consider the conditions that allow a stakeholder approach to ecosystem acceleration to be effective. On the one hand, regional actors must engage in assessments that identify meaningful and cost-effective opportunities that might allow for leveraged impact on their ecosystems, and such interventions must be implemented with adequate resources and effective management practices. However, perhaps more importantly (or in shorter supply in many regions), this approach depends on the production of relational trust among regional stakeholders. Regardless of whether a particular initiative would be "good" for a region matters less than whether engaging in that initiative might advance the objectives of each participating stakeholder, and whether those stakeholders believe that the *other* stakeholders will sustain their commitment and engagement with the chosen intervention.

Achieving this level of trust and commitment requires clarity in the specific strategic objectives (and metrics) for an intervention. With multiple stakeholders at the table, different stakeholders are likely to be interested in pursuing a wide range of goals and objectives. While some of this misalignment in goals may be the result of the structural objectives of each stakeholder (e.g., universities are likely to be far more interested in teaching and research outcomes than corporate stakeholders who will be interested in scaling and effective translation), other differences in goals may result from differences in priorities for the ecosystem itself. For example, it is possible that some stakeholders will be exclusively interested in enabling the highest level of impact in terms of top-line economic growth, while other stakeholders (e.g., government) might be more explicitly interested in promoting shared prosperity (e.g., income growth for those in the lower half of the income distribution). While there are of course no easy answers to how to balance these goals, an excessive misalignment about overall goals is likely to lead to a decline in engagement by at least some stakeholders (and so reduce the impact of the intervention itself). Accordingly, a particularly critical condition for the success of an Engine is alignment about the specific goals and objectives being pursued within that Engine.

Further, while our analysis has focused on the promise and challenges of an individual Engine, the ultimate impact of a Federal program (such as the NSF Engines program) depends ultimately on the performance of the portfolio of investments that are chosen across multiple regions. While each Engine is likely to have distinct metrics associated with their effectiveness (grounded in the distinct strategy they are pursuing), Kremer et al. (2019) offer a promising approach for considering how to undertake such a portfolio assessment when considering the impact of investments in encouraging innovation. Their approach takes advantage of the skewed nature of the returns to such strategic interventions – while a successful program might have a very large impact on a given ecosystem, the costs of "failure" are likely to simply be equal to the costs of the (ineffective) program (i.e., a support program that does not "work" does not cause negative externalities on the system, but instead simply fails to achieve a large positive impact). For example, when Kremer et al. (2019) consider development-oriented innovation investments, 10 programs (out of 55) account for 95% of the impact. A "deep dive" on these 10 "outlier" programs then allows for the estimation of a lower-bound return on the measurable benefits observed *in the most successful regions*. Because the cost of the program for the whole portfolio is well known and constant, assessing the positive returns in only a few locations (and setting the remaining benefits to be zero) in turn provides a reasonable (if conservative) estimate of the return to the entire program portfolio.

Finally, ongoing assessment of the Engines approach should not simply be limited to the quantitative assessment of the rate of return to the program. Both researchers and policymakers are likely to benefit from greater understanding of the "mechanics" of the conditions under which an Engines approach succeeds (or not). Identifying the conditions that allow stakeholders to meaningfully assemble and trust each other, analyzing how differences across regions in terms of ecosystem assessment lead to different strategic interventions, and developing an understanding of "best practices" for implementing any given Engine are each likely to be critical for taking advantage of this type of strategic intervention. Through careful analysis and interpretation of these assessments, we can glean valuable insights into the Engines model's potential, including understanding the conditions under which an Engines model can serve to enhance regional innovative productivity in order to advance economic development and social progress.

REFERENCES

Agudo, A, J Arano, J Avilés, A Bernard, L Iglesias, C López, D Márquez, M Martínez, and M Martínez. 2018. "Looking Back, Looking Forward", *MIT REAP Regional Entrepreneurship Acceleration Program: Team Madrid Executive Summary*.

Acemoglu, Daron. 2003. "Cross-country Inequality Trends." *The Economic Journal* 113 (485): F121–49. https://doi.org/10.1111/1468-0297.00100.

Aghion, Philippe, Ufuk Akcigit, Ari Hyytinen, and Otto Toivanen. 2018. "On the Returns to Invention within Firms: Evidence from Finland." *AEA Papers and Proceedings* 108 (May): 208–12. https://doi.org/10.1257/pandp.20181108.

Aghion, Philippe, Mathias Dewatripont, and Jeremy C. Stein. 2008. "Academic Freedom, Private-Sector Focus, and the Process of Innovation." *The RAND Journal of Economics* 39 (3): 617–35. https://doi.org/10.1111/j.1756-2171.2008.00031.x.

Aghion, Philippe, and Peter Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica* 60 (2): 323–51. https://doi.org/10.2307/2951599.

Agarwal, R. and Ohyama, A., 2013. Industry or academia, basic or applied? Career choices and earnings trajectories of scientists. *Management Science*, *59*(4), pp.950-970.

Agrawal, Ajay, Alberto Galasso, and Alexander Oettl. 2017. "Roads and Innovation." *The Review of Economics and Statistics* 99 (3): 417–34. https://doi.org/10.1162/REST_a_00619.

Agrawal, Ajay, and Avi Goldfarb. 2008. "Restructuring Research: Communication Costs and the Democratization of University Innovation." *American Economic Review* 98 (4): 1578–90. https://doi.org/10.1257/aer.98.4.1578.

Agrawal, A. and Henderson, R., 2002. Putting patents in context: Exploring knowledge transfer from MIT. *Management science*, *48*(1), pp.44-60.

Akcigit, Ufuk, Sina T. Ates, and Giammario Impullitti. 2018. "Innovation and Trade Policy in a Globalized World." Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w24543.

Akcigit, Ufuk, and William R. Kerr. 2018. "Growth through Heterogeneous Innovations." *Journal of Political Economy* 126 (4): 1374–1443. https://doi.org/10.1086/697901.

Almazan, Andres, Adolfo De Motta, Sheridan Titman, and Vahap Uysal. 2010. "Financial Structure, Acquisition Opportunities, and Firm Locations." *The Journal of Finance* 65 (2): 529–63. https://doi.org/10.1111/j.1540-6261.2009.01543.x.

Andrews, M., 2020. "Bar Talk: Informal Social Interactions, Alcohol Prohibition, and Invention".

Arora, Ashish, Sharon Belenzon, and Andrea Patacconi. 2017. "The Decline of Science in Corporate R&D." *Strategic Management Journal* 39 (1): 3–32. https://doi.org/10.1002/smj.2693.

Arora, Ashish, Sharon Belenzon, and Lia Sheer. 2021. "Knowledge Spillovers and Corporate Investment in Scientific Research." *American Economic Review* 111 (3): 871–98. https://doi.org/10.1257/aer.20171742.

Arzaghi, Mohammad, and J. Vernon Henderson. 2008. "Networking off Madison Avenue." *The Review of Economic Studies* 75 (4): 1011–38. https://doi.org/10.1111/j.1467-937X.2008.00499.x.

Audretsch, David B., and Maryann P. Feldman. 1996. "R&D Spillovers and the Geography of Innovation and Production." *American Economic Review* 86 (3): 630–40.

Aulet, W. and Murray, F., 2013. A tale of two entrepreneurs: Understanding differences in the types of entrepreneurship in the economy. *Available at SSRN 2259740*.

Azoulay, Pierre, Christian Fons-Rosen, and Joshua S. Graff Zivin. 2019. "Does Science Advance One Funeral at a Time?" *American Economic Review* 109 (8): 2889–2920. https://doi.org/10.1257/aer.20161574.

Azoulay, P., Greenblatt, W.H. and Heggeness, M.L., 2021. Long-term effects from early exposure to research: Evidence from the NIH "Yellow Berets". *Research Policy*, *50*(9), p.104332.

Bailey, E, D Fehder, E Floyd, Y Hochberg, and D Lee. 2023. "Learning to Quit? A Multi-Year Field Experiment with Innovation Driven Entrepreneurs" Working Paper

Balsmeier, Benjamin, Maria Kurakina, Joel Stiebale, and Lee Fleming. 2021. "The Unintended Consequences of R&D Tax Credits: Exploitation, Markups, and Technological Entrenchment." https://iceanet.org/wp-content/uploads/2022/01/Kurakina.pdf.

Baumol, William J. 1990. "Entrepreneurship: Productive, Unproductive, and Destructive." *Journal of Political Economy* 98 (No. 5, Part 1): 893–921. https://doi.org/10.1086/261712.

Bercovitz, J. and Feldman, M., 2008. Academic entrepreneurs: Organizational change at the individual level. *Organization science*, *19*(1), pp.69-89.

Berman, Eli, John Bound, and Stephen Machin. 1998. "Implications of Skill-Biased Technological Change: International Evidence." *The Quarterly Journal of Economics* 113 (4): 1245–79. https://doi.org/10.1162/003355398555892.

Bernstein, Shai, Xavier Giroud, and Richard R. Townsend. 2016. "The Impact of Venture Capital Monitoring." *The Journal of Finance* 71 (4): 1591–1622. https://doi.org/10.1111/jofi.12370.

Blank, Steve G. 2005. *The Four Steps to the Epiphany: Successful Strategies for Products That Win*. Second Edition. Lulu.com. https://web.stanford.edu/group/e145/cgi-bin/winter/drupal/upload/handouts/Four_Steps.pdf.

Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. "A Toolkit of Policies to Promote Innovation." *Journal of Economic Perspectives* 33 (3): 163–84. https://doi.org/10.1257/jep.33.3.163.

Bloom, Nick, Rachel Griffith, and John Van Reenen. 2002. "Do R&D Tax Credits Work? Evidence from a Panel of Countries 1979–1997." *Journal of Public Economics* 85 (1): 1–31. https://doi.org/10.1016/S0047-2727(01)00086-X.

Borjas, George J. 1987. "Self-Selection and the Earnings of Immigrants." Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w2248.

Bresnahan, T. and Gambardella, A. eds., 2004. *Building high-tech clusters: Silicon Valley and beyond*. Cambridge University Press.

Budden, P. and Murray, F., 2022. Strategically engaging with innovation ecosystems. *MIT Sloan Management Review*, *63*(4), pp.1-7.Bryan, Kevin, and Jorge Guzman. 2021. “Entrepreneurial Migration.” *SSRN Electronic Journal*, August. https://doi.org/10.2139/ssrn.3914010.

Catalini, Christian. 2018. “Microgeography and the Direction of Inventive Activity.” *Management Science* 64 (9): 4348–64. https://doi.org/10.1287/mnsc.2017.2798.

Catalini, Christian, Jorge Guzman, and Scott Stern. 2019. “Hidden in Plain Sight: Venture Growth with or without Venture Capital.” Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w26521.

Cespedes, Frank V., Thomas Eisenmann, and Steven G. Blank. 2012. “Customer Discovery and Validation for Entrepreneurs.” Harvard Business School Background Note. https://www.hbs.edu/faculty/Pages/item.aspx?num=41279.

Chesbrough, Henry William. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, Mass: Harvard Business School Press.

Chinitz, Benjamin. 1961. “Contrasts in Agglomeration: New York and Pittsburgh.” *American Economic Review* 51 (2): 279–89.

Cockburn, Iain M., Jean O. Lanjouw, and Mark Schankerman. 2016. “Patents and the Global Diffusion of New Drugs.” *American Economic Review* 106 (1): 136–64. https://doi.org/10.1257/aer.20141482.

Cohen, S., Fehder, D.C., Hochberg, Y.V. and Murray, F., 2019. The design of startup accelerators. *Research Policy*, *48*(7), pp.1781-1797.

Costinot, Arnaud, Dave Donaldson, Margaret Kyle, and Heidi Williams. 2019. “The More We Die, The More We Sell? A Simple Test of the Home-Market Effect.” *The Quarterly Journal of Economics* 134 (2): 843–94. https://doi.org/10.1093/qje/qjz003.

Davis, Donald R., and Jonathan I. Dingel. 2019. “A Spatial Knowledge Economy.” *American Economic Review* 109 (1): 153–70. https://doi.org/10.1257/aer.20130249.

Delgado, Mercedes, Michael E. Porter, and Scott Stern. 2010. “Clusters and Entrepreneurship.” *Journal of Economic Geography* 10 (4): 495–518. https://doi.org/10.1093/jeg/lbq010.

Delgado, M. and Murray, F., 2022. Mapping the Regions, Organizations, and Individuals That Drive Inclusion in the Innovation Economy. *Entrepreneurship and Innovation Policy and the Economy*, *1*(1), pp.67-101.

Deming, D.J. and Noray, K., 2020. Earnings dynamics, changing job skills, and STEM careers. *The Quarterly Journal of Economics*, *135*(4), pp.1965-2005.

Dornbusch, Rudiger, Stanley Fischer, and Paul A. Samuelson. 1977. “Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods.” *American Economic Review* 67 (5): 823–39.

European Commission. 2022. *What is Smart Specialisation?*. url: https://s3platform.jrc.ec.europa.eu/what-we-do

Executive Office of the President, and Office of Science and Technology Policy. 2009. "A Strategy for American Innovation: Driving towards Sustainable Growth and Quality Jobs." ED511653. ERIC. https://eric.ed.gov/?id=ED511653.

Fazio, Catherine, Jorge Guzman, and Scott Stern. 2019. "The Impact of State-Level R&D Tax Credits on the Quantity and Quality of Entrepreneurship." Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w26099.

Fehder, D., Hausman, N., Hochberg, Y. and Lee, D.J., 2023. University Research, Technological Commercialization, and Location. *The Center for Growth and Opportunity*.

Feld, Brad. 2012. *Startup Communities: Building an Entrepreneurial Ecosystem in Your City*. Startup Revolution Series. Hoboken, New Jersey: John Wiley & Sons, Inc.

Feldman, Maryann P. 1994. *The Geography of Innovation*. Vol. 2. Economics of Science, Technology and Innovation. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-3333-5.

———. 2001. "The Entrepreneurial Event Revisited: Firm Formation in a Regional Context." *Industrial and Corporate Change* 10 (4): 861–91. https://doi.org/10.1093/icc/10.4.861.

———. 2014. "The Character of Innovative Places: Entrepreneurial Strategy, Economic Development, and Prosperity." *Small Business Economics* 43 (1): 9–20. https://doi.org/10.1007/s11187-014-9574-4.

Feldman, Maryann P., and Johanna L. Francis. 2003. "Fortune Favours the Prepared Region: The Case of Entrepreneurship and the Capitol Region Biotechnology Cluster." *European Planning Studies* 11 (7): 765–88. https://doi.org/10.1080/0965431032000121337.

Fernandez, Roberto M. 2001. "Skill-Biased Technological Change and Wage Inequality: Evidence from a Plant Retooling." *American Journal of Sociology* 107 (2): 273–320. https://doi.org/10.1086/324009.

Florida, Richard L. 2005. *Cities and the Creative Class*. New York: Routledge.

Forman, C., Goldfarb, A. and Greenstein, S., 2016. "Agglomeration of invention in the Bay Area: Not just ICT." *American Economic Review*, 106(5), pp.146-151.

Fry, C.V., 2023. Bridging the gap: Evidence from the return migration of African scientists. *Organization Science*, *34*(1), pp.404-432.

Furman, J.L. and MacGarvie, M.J., 2007. "Academic science and the birth of industrial research laboratories in the US pharmaceutical industry." *Journal of Economic Behavior & Organization*, 63(4), pp.756-776.

Furman, Jeffrey L., Markus Nagler, and Martin Watzinger. 2021. "Disclosure and Subsequent Innovation: Evidence from the Patent Depository Library Program." *American Economic Journal: Economic Policy* 13 (4): 239–70. https://doi.org/10.1257/pol.20180636.

Furman, Jeffrey L, Michael E Porter, and Scott Stern. 2002. "The Determinants of National Innovative Capacity." *Research Policy* 31 (6): 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4.

Furman, Jeffrey L., and Scott Stern. 2011. “Climbing atop the Shoulders of Giants: The Impact of Institutions on Cumulative Research.” *American Economic Review* 101 (5): 1933–63. https://doi.org/10.1257/aer.101.5.1933.

Glaeser, Edward L., Sari Pekkala Kerr, and William R. Kerr. 2015. “Entrepreneurship and Urban Growth: An Empirical Assessment with Historical Mines.” *The Review of Economics and Statistics* 97 (2): 498–520. https://doi.org/10.1162/REST_a_00456.

Gompers, Paul, and Josh Lerner. 2001. “The Venture Capital Revolution.” *Journal of Economic Perspectives* 15 (2): 145–68. https://doi.org/10.1257/jep.15.2.145.

Gonzalez-Uribe, J. and Leatherbee, M., 2018. The effects of business accelerators on venture performance: Evidence from start-up Chile. *The Review of Financial Studies*, *31*(4), pp.1566-1603.

González-Uribe, J. and Reyes, S., 2021. Identifying and boosting “Gazelles”: Evidence from business accelerators. *Journal of Financial Economics*, *139*(1), pp.260-287.

Gross, Daniel, and Bhaven Sampat. 2020. “America, Jump-Started: World War II R&D and the Takeoff of the U.S. Innovation System.” Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w27375.

Gruber, Jonathan, and Simon Johnson. 2019. *Jump-Starting America: How Breakthrough Science Can Revive Economic Growth and the American Dream*. New York, NY: PublicAffairs.

Gruber, Jonathan, Simon Johnson, and Enrico Moretti. 2022. “Place-Based Productivity and Costs in Science.” Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w30416.

Guiso, Luigi, Paola Sapienza, and Luigi Zingales. 2009. “Cultural Biases in Economic Exchange?” *The Quarterly Journal of Economics* 124 (3): 1095–1131. https://doi.org/10.1162/qjec.2009.124.3.1095.

Guzman, Jorge. 2023. “The Direct Effect of Corporate Law on Entrepreneurship.” SocArXiv. https://doi.org/10.31235/osf.io/967ph.

Hausman, N., 2022. University innovation and local economic growth. *Review of Economics and Statistics*, *104*(4), pp.718-735.

Hochberg, Y.V., 2016. Accelerating entrepreneurs and ecosystems: The seed accelerator model. *Innovation policy and the economy*, *16*(1), pp.25-51.

Howell, Sabrina T. 2017. “Financing Innovation: Evidence from R&D Grants.” *American Economic Review* 107 (4): 1136–64. https://doi.org/10.1257/aer.20150808.

Howell, S.T., 2020. Reducing information frictions in venture capital: The role of new venture competitions. *Journal of Financial Economics*, *136*(3), pp.676-694.

Hsieh, Chang-Tai, and Enrico Moretti. 2019. “Housing Constraints and Spatial Misallocation.” *American Economic Journal: Macroeconomics* 11 (2): 1–39. https://doi.org/10.1257/mac.20170388.

Hunt, Jennifer, and Marjolaine Gauthier-Loiselle. 2010. "How Much Does Immigration Boost Innovation?" *American Economic Journal: Macroeconomics* 2 (2): 31–56. https://doi.org/10.1257/mac.2.2.31.

Hvide, Hans K., and Benjamin F. Jones. 2018. "University Innovation and the Professor's Privilege." *American Economic Review* 108 (7): 1860–98. https://doi.org/10.1257/aer.20160284.

Iranzo, Susana, and Giovanni Peri. 2009. "Migration and Trade: Theory with an Application to the Eastern–Western European Integration." *Journal of International Economics* 79 (1): 1–19. https://doi.org/10.1016/j.jinteco.2009.05.003.

Jacob, B.A. and Lefgren, L., 2011. The impact of NIH postdoctoral training grants on scientific productivity. *Research policy*, *40*(6), pp.864-874.

Jaffe, Adam B. 1986. "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value." *American Economic Review* 76 (5): 984–1001.

Jaffe, Adam B., Manuel Trajtenberg, and Rebecca Henderson. 1993. "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations." *The Quarterly Journal of Economics* 108 (3): 577–98. https://doi.org/10.2307/2118401.

Jensen, R. and Thursby, M., 2001. Proofs and prototypes for sale: The licensing of university inventions. *American Economic Review*, *91*(1), pp.240-259.

Jones, Benjamin F., and Lawrence H. Summers. 2022. "A Calculation of the Social Returns to Innovation." *Innovation and Public Policy*. University Chicago Press. Eds. Austan Golsbee and Benjamin F. Jones.

Jones, Charles I. 1995. "R & D-Based Models of Economic Growth." *Journal of Political Economy* 103 (4): 759–84. https://doi.org/10.1086/262002.

Kantor, Shawn, and Alexander Whalley. 2022. "Moonshot: Public R&D and Growth." https://drive.google.com/file/d/1hVWGALLLPXkZCVaHhz-rh7BASwPKzneU/view.

Kaplan, Steven N., and Josh Lerner. 2010. "It Ain't Broke: The Past, Present, and Future of Venture Capital." *Journal of Applied Corporate Finance* 22 (2): 36–47. https://doi.org/10.1111/j.1745-6622.2010.00272.x.

Kerr, William R. 2020. "Global Talent and U.S. Immigration Policy." Harvard Business School Entrepreneurial Management. https://doi.org/10.2139/ssrn.3581039.

Kerr, William R., and Scott D. Kominers. 2015. "Agglomerative Forces and Cluster Shapes." *The Review of Economics and Statistics* 97 (4): 877–99. https://doi.org/10.1162/REST_a_00471.

Kerr, William R., Josh Lerner, and Antoinette Schoar. 2014. "The Consequences of Entrepreneurial Finance: Evidence from Angel Financings." *The Review of Financial Studies* 27 (1): 20–55. https://doi.org/10.1093/rfs/hhr098.

Kerr, William R., and William F. Lincoln. 2010. "The Supply Side of Innovation: H-1B Visa Reforms and US Ethnic Invention." Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w15768.

Kerr, William R., Ramana Nanda, and Matthew Rhodes-Kropf. 2014. “Entrepreneurship as Experimentation.” *Journal of Economic Perspectives* 28 (3): 25–48. https://doi.org/10.1257/jep.28.3.25.

Kerr, William R., and Frederic Robert-Nicoud. 2020. “Tech Clusters.” *Journal of Economic Perspectives* 34 (3): 50–76. https://doi.org/10.1257/jep.34.3.50.

Krugman, Paul. 1980. “Scale Economies, Product Differentiation, and the Pattern of Trade.” *American Economic Review* 70 (5): 950–59. https://doi.org/10.7551/mitpress/5933.003.0005.

Kyle, Margaret K. 2007. “Pharmaceutical Price Controls and Entry Strategies.” *The Review of Economics and Statistics* 89 (1): 88–99. https://doi.org/10.1162/rest.89.1.88.

Lanahan, Lauren, and Maryann P. Feldman. 2015. “Multilevel Innovation Policy Mix: A Closer Look at State Policies That Augment the Federal SBIR Program.” *Research Policy* 44 (7): 1387–1402. https://doi.org/10.1016/j.respol.2015.04.002.

Lawhorn, Julie M., Marcy E. Gallo, Adam G. Levin, and Emily G. Blevins. 2023. “Regional Innovation: Federal Programs and Issues for Consideration.” R47495. Congressional Research Service. https://crsreports.congress.gov/product/pdf/R/R47495.

Lerner, Josh. 2013. “The Boulevard of Broken Dreams: Innovation Policy and Entrepreneurship.” *Innovation Policy and the Economy* 13 (January): 61–82. https://doi.org/10.1086/668239.

Lerner, Josh, and Antoinette Schoar. 2005. “Does Legal Enforcement Affect Financial Transactions? The Contractual Channel in Private Equity.” *The Quarterly Journal of Economics* 120 (1): 223–46. https://doi.org/10.1162/0033553053327443.

Lerner, Joshua. 2009. *Boulevard of Broken Dreams: Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed--and What to Do about It*. Kauffman Foundation Series on Innovation and Entrepreneurship. Princeton, N.J.: Princeton University Press.

Li, Danielle. 2017. “Expertise versus Bias in Evaluation: Evidence from the NIH.” *American Economic Journal: Applied Economics* 9 (2): 60–92. https://doi.org/10.1257/app.20150421.

Linder, Staffan Burenstam. 1961. *An Essay on Trade and Transformation*. Stockholm: Almqvist & Wiksell.

Marshall, Alfred. 1920. *Principles of Economics: An Introductory Volume*. 8th ed. Macmillan.

Marx, Matt, and David H. Hsu. 2022. “Revisiting the Entrepreneurial Commercialization of Academic Science: Evidence from ‘Twin’ Discoveries.” *Management Science* 68 (2): 1330–52. https://doi.org/10.1287/mnsc.2021.3966.

Marx, Matt, Deborah Strumsky, and Lee Fleming. 2009. “Mobility, Skills, and the Michigan Non-Compete Experiment.” *Management Science* 55 (6): 875–89. https://doi.org/10.1287/mnsc.1080.0985.

Mello-Klein, Cody. 2023. “NSF Official Wants to Catalyze Research Partnerships to Tackle Pressing Societal Challenges.” *Northeastern Global News*, January 12, 2023. https://news.northeastern.edu/2023/01/12/nsfs-new-tip-directorate/.

MIT REAP. 2023. “Home.” MIT REAP: Regional Entrepreneurship Acceleration Program. 2023. https://reap.mit.edu/.

Mokyr, Joel. 2002. *The Gifts of Athena: Historical Origins of the Knowledge Economy*. Princeton, NJ: Princeton University Press.

Moretti, Enrico. 2004. “Workers’ Education, Spillovers, and Productivity: Evidence from Plant-Level Production Functions.” *American Economic Review* 94 (3): 656–90. https://doi.org/10.1257/0002828041464623.

———. 2012. *The New Geography of Jobs*. 1st Mariner books ed. Boston, Mass: Houghton Mifflin Harcourt.

Moretti, E., 2021. The effect of high-tech clusters on the productivity of top inventors. *American Economic Review*, *111*(10), pp.3328-3375.

Mowery, David, and Nathan Rosenberg. 1993. “The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies.” *Research Policy* 22 (2): 102–53. https://doi.org/10.1016/0048-7333(79)90019-2.

Mowery, D.C., Nelson, R.R., Sampat, B.N. and Ziedonis, A.A., 2001. The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh–Dole act of 1980. *Research policy*, *30*(1), pp.99-119.

Murphy, Kevin M., Andrei Shleifer, and Robert W. Vishny. 1991. “The Allocation of Talent: Implications for Growth.” *The Quarterly Journal of Economics* 106 (2): 503–30. https://doi.org/10.2307/2937945.

Murray, F., 2004. The role of academic inventors in entrepreneurial firms: sharing the laboratory life. *Research policy*, *33*(4), pp.643-659.

Murray, Fiona. 2013. “Evaluating the Role of Science Philanthropy in American Research Universities.” *Innovation Policy and the Economy* 13 (1): 23–60. https://doi.org/10.1086/668238.

Murray, F. and Budden, P., 2017. *A systematic MIT approach for assessing ‘innovation-driven entrepreneurship in ecosystems (iEcosystems)*. Working paper Published by MIT’s Laboratory for Innovation Science & Policy. Retrieved August 17, 2021,

Myers, Kyle R., and Lauren Lanahan. 2022. “Estimating Spillovers from Publicly Funded R&D: Evidence from the US Department of Energy.” *American Economic Review* 112 (7): 2393–2423. https://doi.org/10.1257/aer.20210678.

Nelson, Richard R., ed. 1993. *National Innovation Systems: A Comparative Analysis*. 1st ed. New York: Oxford University Press.

NSF. 2018. “Chapter III - NSF Proposal Processing and Review.” In *Proposal & Award Policies & Procedures Guide*, 181. https://www.nsf.gov/pubs/policydocs/pappg18_1/pappg_3.jsp.

NSF. 2022. *Dear Colleague Letter: NSF Regional Innovation Engines (NSF Engines) Program.* url: https://www.nsf.gov/pubs/2022/nsf22082/nsf22082.jsp

Oosterbeek, H., Van Praag, M. and Ijsselstein, A., 2010. The impact of entrepreneurship education on entrepreneurship skills and motivation. *European economic review*, *54*(3), pp.442-454.

Pavitt, K., 1980. “Industrial R & D and the British economic problem.” *R&D Management*, 10, pp.149-158.

Porter, Michael E. 1998. *The Competitive Advantage of Nations*. 1st Free Press ed. New York: Free Press.

Puri, Manju, and Rebecca Zarutskie. 2012. “On the Life Cycle Dynamics of Venture-Capital- and Non-Venture-Capital-Financed Firms.” *The Journal of Finance* 67 (6): 2247–93. https://doi.org/10.1111/j.1540-6261.2012.01786.x.

Ricardo, David. 1817. *On the Principles of Political Economy and Taxation*. John Murray. https://books.google.com/books?id=cUBKAAAAYAAJ.

Roberts-Chapman, Melissa, and Ryan Buscaglia. 2023. “What the CRS Report on Regional Innovation Ecosystems Gets Right and Misses.” *Federation of American Scientists* (blog). April 17, 2023. https://fas.org/publication/crs-regional-innovation-ecosystems/.

Roberts, Edward B. 1991. *Entrepreneurs in High Technology: Lessons from MIT and Beyond*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195067040.001.0001.

Roche, M.P., 2023. Academic entrepreneurship: Entrepreneurial advisors and their advisees’ outcomes. *Organization Science*, *34*(2), pp.959-986.

Romer, Paul M. 1990. “Endogenous Technological Change.” *Journal of Political Economy* 98 (5, Part 2): S71–102. https://doi.org/10.1086/261725.

Rosenberg, Nathan. 1990. “Why Do Firms Do Basic Research (with Their Own Money)?” *Research Policy* 19 (2): 165–74. https://doi.org/10.1016/0048-7333(90)90046-9.

Rosenberg, Nathan, and Richard R. Nelson. 1994. “American Universities and Technical Advance in Industry.” *Research Policy* 23 (3): 323–48. https://doi.org/10.1016/0048-7333(94)90042-6.

Saxenian, AnnaLee. 1996. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128, With a New Preface by the Author*. Cambridge, Mass.: Harvard University Press.

Schieble, Sue. 2014. “Quincy College expands innovative biotechnology program” *The Patriot Ledger*. April 5, 2014. url: https://www.patriotledger.com/story/news/2014/04/05/quincy-college-expands-innovative-biotechnology/37668485007/

Senor, Dan, and Saul Singer. 2009. *Start-up Nation: The Story of Israel’s Economic Miracle*. 1st ed. New York: Twelve.

Stam, E., 2015. Entrepreneurial ecosystems and regional policy: a sympathetic critique. *European planning studies*, *23*(9), pp.1759-1769.

Starr, Evan, Natarajan Balasubramanian, and Mariko Sakakibara. 2017. “Screening Spinouts? How Noncompete Enforceability Affects the Creation, Growth, and Survival of New Firms.” *Management Science* 64 (2): 552–72. https://doi.org/10.1287/mnsc.2016.2614.

Suarez-Villa, L., 1990. “Invention, inventive learning, and innovative capacity”. *Behavioral Science*, 35(4), pp.290-310.

Suarez-Villa, L., 1993. “The dynamics of regional invention and innovation: Innovative capacity and regional change in the twentieth century.” *Geographical Analysis*, 25(2), pp.147-164.

Tartari, Valentina, and Scott Stern. 2021. “More than an Ivory Tower: The Impact of Research Institutions on the Quantity and Quality of Entrepreneurship.” Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w28846.

Thursby, J. G., & Thursby, M. C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management science*, *48*(1), 90-104.

USPTO. 2015. *Listing of All U.S. Metropolitan and Micropolitan Areas, Total Utility Patent Counts, 2000 – 2015.* url: https://www.uspto.gov/web/offices/ac/ido/oeip/taf/cls_cbsa/allcbsa_gd.htm

Wang, Dan. 2015. “Activating Cross-Border Brokerage: Interorganizational Knowledge Transfer through Skilled Return Migration.” *Administrative Science Quarterly* 60 (1): 133–76. https://doi.org/10.1177/0001839214551943.

Wernsdorf, Kathrin, Markus Nagler, and Martin Watzinger. 2022. “ICT, Collaboration, and Innovation: Evidence from BITNET.” *Journal of Public Economics* 211 (July): 104678. https://doi.org/10.1016/j.jpubeco.2022.104678.

Yu, S., 2020. How do accelerators impact the performance of high-technology ventures? *Management Science*, *66*(2), pp.530-552.

Table 1. Timeline of Federal Place-Based Innovation Policy

US Government Sponsored Programs

Year	*Program*	*Budget*	*Sponsor*	*Objective*
2010	i6 Challenge	~ $33M / year	Department of Commerce – Office of Innovation and Entrepreneurship	Awards grants that build regional capacity to translate innovations into jobs through proof-of-concept and commercialization assistance to innovators and entrepreneurs
2010	Regional Innovation Clusters	3.5M / year	Small Business Administration	Create regional networks of businesses and other organizations that work together to maximize their strengths and resources, allowing them to compete on a larger scale.
2010	Building to Scale[10] - Venture & Capital Challenges	$50M / year	Department of Commerce – Office of Innovation and Entrepreneurship	Increase regional capacity to strengthen ecosystems that equitably and inclusively support diverse technology innovators, entrepreneurs, and startups.
2010	Energy Regional Innovation Cluster[11]	$129.7M over 5 years	Department of Energy	Foster a regional innovation cluster focused on innovation in energy efficient building technologies and systems design.
2022	Regional Clean Energy Innovation Program	Up to 10M per consortia	Department of Energy	Enhance the economic, environmental, and energy security of the US, accelerate the development clean energy technologies through the formation of partnerships
2022	Regional Technology and Innovation Hubs[3,4,5]	$10B over 5 years	Economic Development Agency & National Institutes of Science and Technology	Drive regional technology- and innovation-centric growth by strengthening a region's capacity to manufacture, commercialize, and deploy critical technologies
2022	Regional Innovation[3,4,5] Engines Program	$6.5B combined for RIE & NSF Translation Program	National Science Foundation	Address pressing national and societal challenges; Advance critical technologies like semiconductors, artificial intelligence, advanced wireless, and biotechnology; Cultivate partnerships across industry, academia, government, nonprofits, civil society, and communities of practice;

Foreign Government Programs

Year	*Program*	*Budget*	*Sponsor*	*Objective*
2018	Super-clusters	C$ 950	Canada - Ministry of Innovation, Science and Economic Development	Create "Superclusters" - dense areas of business activity where innovation happens and where many of the middle-class jobs of today and tomorrow are created
2017	Innovation Accelerators Program[12]	£ 100M	United Kingdom – Department of Science, Innovation and Technology	Build a dynamic innovation economy that provides growth across the whole country by unleashing the power of the private sector.
2019	Smart Specialization	Up to 10M € per project	European Union – administered by Member States	Member regions create and implement a development plan by identifying niche areas of competitive strength, fostering innovation, partnerships, coordination between private and public stakeholders.
2020	Powering the Regions Fund / Hydrogen Head-start	3.4B AUD	Australian Government - Department of Infrastructure, Regional Planning and Cities	Three new grants to support industrial decarbonization and clean energy industries in the regions. Underwrite large-scale renewable hydrogen projects through competitive hydrogen production contracts.

[10] America COMPETES Reauthorization Act of 2010 - increased funding for science, engineering, and mathematics (STEM) education programs.

[11] In September 2009, Obama Administration announced an American Innovation Strategy that doubled research and innovation budgets of 3 key research agencies – National Science Foundation, Department of Energy's Office of Science, National Institute of Science and Technology. It also set an objective of investing more than 3% of GDP on public and private R&D

[12] In 2019, UK government's "Leveling Up" campaign allocated £ 4.8B to reduce economic imbalances between regions and social groups.

Table 2. Traditional Versus Ecosystem Acceleration Grants

	Traditional Research Grant	**Strategic Regional Intervention**
Goal	Scientific development or tech transfer	Developing regional innovation capacity
Mechanism	Supporting specific research projects (hoping for spillovers), or direct tech transfer.	Enabling the spillover process of any project.
Target Agent	University researchers	Groups of local stakeholders: universities, corporate, risk capital, government, and startups.
Grantees	Individuals or companies	Regional organizations
Timeline	2-5 years	7-15 years

Table 3. Systematic Elements of a Regional Innovation Ecosystem

Foundational Institutions: Does innovation occur on a safe and productive playing field?

Area	**Key Evidence**
Are there strong property rights, rule of law, and a developed corporate code?	Lerner and Schoar, 2005; Guzman, 2023.
Are there effective intellectual property rights?	Kyle, 2007; Cockburn et al., 2016.
Do rules permit or hinder the movement of scientists through such policies as non-competes?	Marx et al., 2009; Starr et al., 2017.
Are there strong local universities that promote skilled workers, innovation, and entrepreneurship?	Tartari and Stern, 2022.
Does the country trade relationships offer an opportunity for trade and idea exchange?	Akcigit et al 2018; Wang, 2015.

Regional Innovative Capacity: Does a region have the ingredients to product innovation?

Area	**Key Evidence**
Human Capital	
Are there skilled inventors to carry out innovations?	Moretti, 2004; Iranzo and Peri, 2009.
Is the region receiving additional talent through migration?	Hunt and Gauther-Loiselle, 2010; Kerr and Lincoln, 2010.
Are there local leaders willing to drive and effectuate change?	Feldman, 2001; Feldman and Francis, 2003.
Financial Capital	
Does the state support innovation through the tax system?	Bloom et al. 2002; Balsmeier et al., 2022.
Is there a meaningful engagement of private philanthropy for the development of innovation?	Murray 2013.
Are there matching funds of Federal grants by local government?	Lanahan and Myers, 2022; Feldman and Lanahan, 2015.
What programs support the translation of research into company readiness (such as SBIR)?	Lanahan and Feldman, 2015; Howell, 2017.
Is there a strong venture capital and angel financing industry?	Gompers and Lerner, 2001; Kaplan and Lerner, 2010; Kerr et al., 2015.
Infrastructure	
Is there a good road infrastructure and other public services?	Agrawal et al., 2018.
Is there good connectivity to other regions through airports?	Bernstein et al., 2016.
Are there spaces to develop and experiment with new ideas and accelerate young startups?	Kerr, Nanda, and Rhodes-Kropf, 2014; Fehder and Hochberg, 2014; Catalini et al., 2018.
Is there a social setting where social interactions can occur?	Andrews, 2022
Is there good internet access?	Agrawal and Goldfarb, 2008; Wernsdorf et al., 2022.
Culture and Incentives	
Is there a culture of trust, entrepreneurship, and innovation?	Guiso et al. 2009; Chinitz, 1961; Glaeser et al., 2015; Senor and Signer, 2008; Saxenian, 1994; Feldman, 2014.
Does the region's reward structure incentivize highly skilled individuals to move into it?	Borjas, 1987; Kerr 2020.
Are there high-quality amenities and living conditions?	Florida, 2004; Bryan and Guzman, 2021.
Demand	
What are the local home market conditions that facilitate innovation in specific products?	Costinot et al. 2019; Cespedes et al. 2012.

Entrepreneurial Capacity: How do new ideas translate into new firms?

Area	**Key Evidence**
Is the economic reward structure encouraging highly skilled individuals to be entrepreneurs?	Baumol, 1990; Murphy, Shleifer, and Vishny, 1991.
Are the incentives set up so that innovators seek to commercialize their inventions?	Hvide and Jones, 2018; Aghion et al., 2018.

Corporate Capacity: How do incumbents incorporate and develop new ideas?

Area	**Key Evidence**
Are incumbents focused on basic research or mostly on product development?	Rosenberg, 1990; Jaffe, 1986; Arora et al., 2022.
Is there a history of 'open innovation' in this industry and region?	Chesborough, 2003.
Is there a tradition of alliances, licensing, and acquisitions in this region?	Puri and Zarutskie, 2012; Almazan et al., 2010.

Regional Comparative Advantage: What is this region uniquely positioned to do well?

Area	**Key Evidence**
What industry clusters exist in the region, and how do they relate to the global economy?	Delgado et al., 2014.
What are the inherent natural advantages of a region due to its location, and what are the cultural and functional capabilities of this region?	Porter, 1997; Kerr and Robert-Nicoud, 2020.
What are the cost-based advantages of a region leading to comparative advantage?	Porter, 1997.

Table 4. Acceleration Engines: Exemplars and Empirical Evidence

	Program Type	Regional Bottlenecks	Intended Strategic Impact and Outcomes	Key Empirical References	Representative Federal Programs[a]
	Commercialization and Acceleration Programs	• While region has strong innovative capacity and supply of entrepreneurial talent, start-ups lack networks and mentor required to scale • Commercialization of regional innovation lags due to lack of early-stage commercial experimentation • Innovators and entrepreneurs lack a "community" to provide support and opportunities for peer learning	• Increased growth rate of "accelerated" companies, including faster revenue and equity growth, employment growth, and achievement of commercialization milestones • Increased focus on experimentation also encourages "fast failure" among ventures that are unlikely to scale • Higher rate of follow-on financing for accelerated companies, and more generally for the region	Cohen et al. (2019); Fehder (2023); Fehder and Hochberg (2014); Gonzalez-Uribe and Leatherbee, (2018); Gonzalez-Uribe and Reyes (2021); Lyons and Zhang (2017); Hochberg (2016); Howell (2020); Yu (2020)	NSF CORPS NSF Innovation Corps
	Human Capital and Skilled Workforce Development	• While region has identifiable areas of innovative comparative advantage, critical skills and competencies are missing in local workforce • Lack of training opportunities locally lead to emigration of talented individuals or focus on non-innovation sectors • Even with strong overall education system, lack of specific training in innovation, commercialization and entrepreneurship	• Increasing supply of "trained" graduates in specific skills and competencies that meet the specific bottleneck needs ot local innovation and commercialization efforts • Increased retention of high-potential university graduates in key fields, and attraction of high-potential graduates from other regions • Increasing supply and quality of "trained" innovators and entrepreneurs based on specialized programs to address this shortage	Agarwal and Ohyama (2013); Azoulay, et al. (2021); Deming and Noray (2020); Stephan (2012); Fry (2023); Jacob and Lefgren (2011); Murray (2004); Ding and Stuart (2006); Murray, Ding, and Stuart (2008); Azoulay et al, (2013); Oosterbeek et al. (2010); Roche (2023); Dimitriadis and Koning (2020); Chatterji et al. (2019).	GRFP NSF Graduate Research Fellowship Program
	Innovation Partnerships	• While region has strong individual innovators and entrepreneurs, commercialization and scaling is hampered by lack of effective technology transfer or utilization of potentially shared resources and • Critical innovaiton bottlenecks arise because of lack of "cooperation" among innovation stakeholders, including the process of technology transfer • Strong regional comparative advantage is not being reinforced or extended through targeted cluster programs	• Increased flow of high-quality innovation through multiple stages of the innovation pipeline within the region • Number of executed (and utilized) technology transfer agreements with local start-ups and larger firms with regional presence • Establishment, successful utilization, and collaborations through shared specialized research infrastructure • Increased participation and growth by firms (both start-up and established) within targeted clusters and adjacent clusters	Hausman (2022); Mowery et al. (2001); Moretti (2021); Delgado et al. (2010); Delgado et al. (2014); Guzman (2023); Delgado and Porter (2021); Agrawal et al. (2016); Bercovitz and Feldman (2008); Furman and Stern (2007); Thursby and Thursby (2002); Jensen and Thursby (2001); Hvide and Jones (2018); Nagaraj and Tranchero, 2023	Build to Scale
	Investment and Risk Capital	• While region has strong supply of early-stage start-ups, lack of risk capital hampers growth and acceleration of otherwise promising ventures • Risk capital is allocated unequally to innovators and entrepreneurs from different backgrounds (e.g., by gender, race, educational background), regardless of the "quality" of the idea or venture	• Increasing the scale and impact of local innovative start-ups by experiencing higher financing rounds and employment growth. • Increasing the number of venture-backed companies, the number of SBIR granted companies, and the number of angel-funded companies. • Increasing the total supply of angel financing and venture capital available in the region. • Maintaining the presence of growing companies that choose not to migrate to other regions to obtain their necessary financing. • Attracting capital flows from investors in other regions through venture capital networks between foreign and local investors.	Bernstein et al. (2016); Gompers and Lerner (2001); Howell (2017); Kortum and Lerner (2001); Lanahan and Feldman (2015); Lerner (2009); Myers and Lanahan (2022); Lerner (1995); Sorenson and Stuart (2001); Samila and Sorenson (2011);	NSF America's SEED FUND SBIR.STTR

[a] The programs listed are key Federal programs that serve the objective of the broad strategic intervention. However, to date such programs have by and large been location-agnostic and funds have been invested at the level of individual proposals rather than as the strategic intervention underlying a Regional Engine strategy.