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Technology transfer from national/federal labs and public research institutes: Managerial and policy implications

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ABSTRACT

While technology transfer at universities has received considerable attention in the innovation and entrepreneurship literature, we know much less about technology transfer at national/federal labs and (non-university) public research institutes. In this article and the related special section, we aim to fill this void. We provide a rationale for our special section on technology transfer from national/federal labs and public research institutes, summarize the papers in the special section, highlight research questions, theories, data and methods, key findings and conclusions. We conclude by outlining a research agenda for multi-level research on agents, institutions, and regions to improve our understanding of the managerial and public policy implications of technology transfer from these institutions.

1. Introduction

There is a vast literature on technology transfer from universities to firms (Grimaldi et al., 2011; Perkmann et al., 2013, 2021). These studies have yielded important insights on the managerial and public policy implications of technology transfer and "academic entrepreneurship," more generally (Link et al., 2015; Siegel and Wright, 2015a). Unfortunately, with the exception of a flurry of studies many years ago (e.g., Bozeman and Crow, 1991; Crow and Bozeman, 1998; Rahm et al., 1988; Jaffe et al., 1998; Adams et al., 2002), scholars of innovation and entrepreneurship have not devoted considerable attention to technology transfer at national/federal labs and (non-university) public research institutes. The purpose of this special section is to fill this void, given the importance of such institutions in innovation ecosystems. We also discuss the managerial and public policy implications of key findings and connect them to potential avenues for future research.

To highlight the important role of federal labs in national innovation systems, a recent study of major innovations in the U.S. since World War II concluded that federal labs were responsible for developing key "general purpose technologies," including electronics, computers and the Internet, airplanes, biotechnology, pharmacogenomics, nuclear energy, and laser technologies (Price and Siegel, 2019). A 2021 report from the National Academies of Science, Engineering, and Medicine (NASEM, 2021) recommended that the federal government (or other parties) collect additional quantitative and qualitative data from the federal labs, in order to better understand, and ultimately stimulate, more lab-based technology transfer.

Although the NASEM report was focused on the U.S., we believe that such efforts should be undertaken globally. Governments in OECD nations have invested heavily in such public research organizations and they are key component of national innovation systems. In the U.S., federal/national labs received just slightly more government funding

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than universities ($37 billion for federal labs, versus $36 billion for universities). Elsewhere, national labs and other public research organizations receive substantially more government funding for research than universities. In France, the French National Centre for Scientific Research (CNRS), which has 10 research institutes, receives about 80 % of all public funds for R&D. In Germany, Max Planck Institutes, Hemholtz Centers, and Fraunhofer Institutes also receive a substantial share of public funds for R&D. The Chinese Academy of Sciences oversees some 120 research institutes, including all of China's "big science" facilities. In 2018, China announced that its 200 national key laboratories will increase to around 700 by the end of 2020.

Like universities, federal/national labs and public research institutes have a technology transfer mission. In 1980, the same year the Bayh-Dole Act was enacted in the U.S., the U.S. Congress also adopted the Stevenson-Wydler Act, which sought to streamline technology transfer from federal laboratories to industry and mandated that labs establish technology transfer offices. In 1986, Congress passed the Federal Technology Transfer Act (FTTA), which provided direct financial incentives for scientists at federal labs to patent. FTTA also established Cooperative Research and Development Agreements (CRADAs) between firms and federal labs (Mowery et al., 2001; Mowery et al., 2001). In 2000, the Technology Transfer Commercialization Act was passed, which made it easier and more attractive for companies to patent and/or license a technology that was developed at a federal lab (e.g., commercialization resulting from a CRADA).

Similar laws were enacted in other OECD nations, which were designed to stimulate technology transfer from public sector, non-university research institutions. In 2015, China substantially revised its law on promotion of commercialization of S&T results, which gave substantial leeway to public research institutions and universities to manage and profit from the commercialization process. OECD nations have also adopted additional programs to support the commercialization of research at such facilities. For example, in Germany, the Helmholtz Association of German Research Centers, established in 1995 to formalize existing relationships between 19 globally-renowned independent research centers, has sponsored several technology transfer initiatives. These include Helmholtz Innovation Labs (for partnerships with industry), as well as three initiatives to fund and nurture startups and help them overcome the "valley of death": the Hemholtz Validation Fund, a Proof-of-Concept Initiative, and Hemholtz Enterprise. In the U.S., the Department of Energy (DOE), which manages many of the nation's largest federal labs, recently launched two initiatives to enhance commercialization and entrepreneurship associated with federal lab research: Lab Corps (DOE's version of NSF's I-Corps Program), which provides entrepreneurial training for faculty, graduate students, and post-docs and the Small Business Vouchers Pilot project, which provides special financial support for small businesses that have not traditionally worked with federal labs.

Despite substantial global investment in national/federal labs and (non-university) research institutes, as well as legislative reforms and new programs in many nations to stimulate commercialization and entrepreneurship, there has been little systematic academic analysis of the antecedents and consequences of technology transfer at these institutions. Thus, it is timely to publish a special section on these topics in *Research Policy*, which has published seminal papers on technology transfer. We believe that an assessment of institutional and public policies, as well as managerial practices at the facilities, can yield new theoretical and empirical insights on technology transfer. It is also important to analyze how technology transfer at federal/national labs and research institutes may differ from university technology transfer.

In the reminder of this article, we provide focused summaries of the papers presented in the special section, highlighting research questions, theories, data and methods, key findings and conclusions. We conclude by outlining a research agenda for multi-level research on agents, institutions, and regions to improve our understanding of the managerial and public policy implications of technology transfer from these institutions.

2. Contributions to the special section

In this section, we present focused summaries of the papers contained in the special section. The research questions, data and methods, and key findings of the papers are summarized in Table 1.

The first paper in the special section is titled "Assessing Differences between University and Federal Laboratory Postdoctoral Scientists in Technology Transfer," co-authored by Haneul Choi, Elle Yoon, Donald Siegel, David Waldman, and Marie Mitchell. There are three novel aspects of this paper. The first is that the authors compare the technology transfer process at universities and federal/national labs. Second, unlike almost all studies of university technology transfer, which focus on faculty, this article analyzes post-doctoral fellows at universities and federal/national labs and their involvement in the commercialization of research. It is important to note that postdocs constitute a reservoir of cheap labor to support research at universities and federal labs, but may also be involved technology transfer (Siegel and Wright, 2015a, 2015b). Third, the authors examine identity and sensemaking theories in organizational behavior, in the context of technology transfer. With rare exceptions (e.g., Jain et al., 2009) technology transfer scholars have ignored such "micro" theories.

Their qualitative analysis is based on extensive interviews of post-doctoral scientists and their supervisors/principal investigators (PIs) at two major research universities and four large federal labs. A key finding is that federal lab scientists are more engaged in mission-driven research and motivated by a sense of public service than their university counterparts, who are more likely to be engaged in curiosity-driven research. Thus, the public missions of federal labs appear to impose additional barriers to technology transfer. The authors also find that federal lab scientists are more conflicted when pursuing technology transfer, compared to their university counterparts. Such cognitive dissonance often arises because of tension between the norm of open science and research commercialization. According to the authors, another impediment to technology transfer at federal labs is that PIs and senior scientists at these facilities are not highly incentivized to engage in technology transfer. Consistent with the NASEM report (NASEM), the findings of this study underscore the importance of extensive surveys of Ph.D. scientists and engineers, to improve our understanding of managerial and organizational issues relevant to technology transfer, especially in federal labs. The study also has implications for the training of scientists and those who manage them, including technology transfer officers at universities and federal labs.

The second paper in the special section, by Kaihua Chen, Chao Zhang, Ze Feng, Yi Zhang, and Lutao Ning, is titled "Technology Transfer System and Modes of National Research Institutions: Evidence from the Chinese Academy of Sciences." This article has several unique features. The first is that it sheds light on how institutional features of the system of national labs influence the functional design of the technology transfer system (TTS). To some degree, the multilevel TTS (Headquarters, branch office, and institute/lab) is a reflection of the institutional structure of the Chinese Academy of Sciences (CAS), which functions as a system of national labs. Within this multilevel TTS, the role of each unit in the system is determined by its relative position and resource endowment in CAS.

For example, the TTS headquarters of CAS is mainly responsible for connecting the lab with relevant national government agencies. This unit provides general guidance and top-down design, as well as construct academy-wide platforms. At the level of branch-offices, which are regionally-based, the TTS unit is responsible for cooperating with local governments or local enterprises and promoting technology transfer, based on local resource endowment. The TTS actors within the institute/lab-level are in charge of the transfer and commercialization management of specific technologies, as well as providing various support services.

Table 1
Summaries of the papers in the special section.

Authors	Research questions	Data/method	Main findings
Choi, Yoon, Siegel, Waldman, and Mitchell	What are the key differences between technology transfer at universities and federal labs? How important are identify and sense-making theories in technology transfer?	Qualitative analysis of 49 interviews of postdoctoral scientists and their supervisors (PIs) at two major research universities and four large federal labs in the U.S.	Federal lab scientists are more influenced by mission-driven research and their sense of public service, as compared to university scientists, who are motivated more by curiosity-driven research. These motivational differences may constitute significant barriers to technology transfer in federal labs. Federal lab scientists experience more cognitive dissonance in pursuing commercialization of their research than their university counterparts, and have more sophisticated resolution strategies for dealing with such dissonance.
Chen, Zhang, Feng, Zhang, and Ning	How institutional features of the system of national labs influences the functional design of the technology transfer system (TTS)? What are the operational mechanisms and modes of the TTS, in response to the dynamic changes of the national innovation system?	Qualitative analysis of TTS at Chinese Academy of Sciences (CAS), with detailed analysis of 6 specific cases of research institutes/ centers.	First, the paper finds that institutional factors, such as the multi-layered organization structure or the particular roles in NIS, influence the formation of the multi-level TTS in the CAS. Second, the paper identifies and illustrates three typical NRI technology transfer modes of the CAS, and the evolution of these modes; Third, the paper finds that different modes have diverse demands for technological cognition and resource allocation capability, which can be satisfied by the co-specialized interaction among the three levels of the TTS.
Shin, Lee, Jung, and Hwang	Does scientific discovery and subsequent patenting increase follow-on discovery (citations and patents) by researchers in the field, and, if so, in what ways?	Large scale, overtime data on scientific papers and patents, subsampled to create a federal lab sample of 370 patent-related papers and 370 non-fed lab papers from a coarsened-grain match. Diff-in-diff is used to examine pre- vs. post-publication rates around a granted patent.	This paper revisits and re-assesses the impact of federal/national labs with big data and very solid research design to examine direct and indirect benefits. The main effect of federal lab patent paper on post-patent acceptance publication is lower for federal lab than a matched sample in overlapped tech domains; but higher in non-overlapped tech domains, and also in more distant labs and with less well-connected scientists.
Subramanian, Nishant, van de Vrande, and Hang	How is technology transferred from public research institutes to small and medium enterprises (SMEs) What are the characteristics and conditions of technology transfer that determine the intangible benefits attained by technology transfer intermediary agents?	Mixed methods-case studies (qualitative comparative analysis) and survey data from Singapore	The authors find strong evidence of the mutually reinforcing nature of intermediary agent-recipient benefits. Their findings support the notion that technology transfer plays a significant role in developing scientific, technical and social capital (Dietz and Bozeman, 2005; Choudhry and Ponzio, 2020; Feller, 2022).

The second unique aspect of the paper is that it demonstrates the diversity and dynamics of the modes of technology transfer within CAS, in response to the structural transformation of China's national innovation system. The three technology transfer modes in the CAS follow an evolutionary sequence from the CAS-regional cooperation mode, to the incubation mode, and to the platform-driven mode. The first is the CAS-regional cooperation mode, which dates back to the beginning of the establishment of the CAS, and this mode has regained attention since the S&T system reform in the 1980s. With the acceleration of S&T system reform in China and in the CAS, the incubation ecosystem mode emerged in the early 21st century. Amidst the revision of the Scientific and Technological Progress Law and the progress in catch up technologically, the platform-driven mode has emerged in the CAS over the past decade. The evolution of these three modes mirrors the progress of the S&T system reform in China as well as the mission repositioning of the CAS.

These issues are based on qualitative analysis of the CAS as a system of national labs, and a number of cases of research institutes, incubations centers, and tech. platforms. These cases offer a rare observation of the operations of a diverse set of institutes/centers with very different missions in the CAS, which may lead to questions about the core mission of the CAS system itself. For more than 40 years, the mission of CAS has been shifting to try to adapt to the rapid development of Chinese economy and the increasingly more diverse demand for S&T advancement. The diversity and dynamics of modes of technology transfer are only a reflection of this underlying transition.

The third paper in the special section, by Seungryul Ryan Shin, Jisoo Lee, Yura Rosemary Jung, and Junseok Hwang, is titled "The diffusion of scientific discoveries in government laboratories: The role of patents filed by government scientists." Patenting and follow-on discoveries is a major topic of interest in technology transfer research (Jaffe et al., 1993; Feldman et al., 2002; Sorenson and Fleming, 2004). This excellent empirical study examines a central research question applying to federal labs: Does scientific discovery and subsequent patenting increase follow-on discovery (citations and patents) by researchers in the field, and, if so, in what ways? Prior research has certainly suggested this is so, such as pieces showing national policies stimulating lab science, such as the Bayh-Dole Act, increase research in relevant areas (Mowery et al., 2001), and that federal labs, such as NASA units, can have positive spillovers on other industry research (Jaffe et al., 1998). Unfortunately, the efficacy of such labs, relative to private company labs, has not been examined carefully, and where the benefits spillover the most is still debated.

The authors employ state-of-the-art methods to address their research question: a matched sample, difference-in-difference approach, which compares research papers and patents from those papers by scientists associated with federal/national labs to papers and patents by those not associated with such labs. The authors sampled all federally funded research and development (FFRDC) papers using Microsoft's MAG and the Reliance on Science (RoS) database and, with coarsened grained matching, constructed a sample of 370 federal and 370 non-federal science papers and then follow-on citations with patents.

Using these data and a difference-in-difference model, based on follow-on inventions from the moment that paper's patent is granted, they were able to demonstrate some counterintuitive contingent effects: while being an FFRDC scientist didn't matter overall for citations with patents, it increased follow-on cite patents in non-overlapped technology domains, but decreased it in overlapped ones – in both cases relative to the counterfactual (non-FFRDC) science group. Intriguing. In addition, if researchers doing follow-on work were in more distant locations or less well-connected in the science fields, those researchers relied more on the FFRDC lab research. These two, and other findings, provide evidence that public policy benefits were accruing to less central and less privileged members of the tech transfer system, as societal members would hope (Jaffe and Lerner, 2004; Wry et al., 2014). However, the results also suggest less beneficial outcomes of FFRDC work occurred in core locations and research domains, challenging some work on cluster vitality (Heaton et al., 2019) and science park intermediaries (Armanios et al., 2017).

The fourth and final paper in the special section, by Annapoornima Subramanian, Rohit Nishant, Vareska van de Vrande, and Chang Chieh Hang, is titled "Technology Transfer from Public Research Institutes to SMEs: A Configurational Approach to Studying Reverse Knowledge Flow Benefits." This study is unusual in three respects. First, it focuses on technology transfer from public research institutes to small and medium enterprises (SMEs). To a large extent, SMEs have been virtually ignored in the technology transfer literature. Second, the paper also focuses on the role of intermediary agents, such as research scientists and engineers (RSEs). Previous studies of technology transfer intermediaries have overlooked the reverse knowledge flow benefits enjoyed by the RSEs who facilitate technology transfer. These benefits can be technical (R&D skills, interdisciplinary research), business-related (business skills, commercialization knowledge, understanding of differences between research lab and practice), and social (soft skills, networking benefits, career advancement). Third, the paper uses a configurational approach based on fuzzy set qualitative case analysis (fsQCA), which makes it possible to examine the (a)symmetries of drivers for higher and lower benefit research. Most research tends to focus on the upside and positive case, and cannot identify unique bundles of drivers for the downside, less beneficial research.

The main objective of the paper is to assess the characteristics and conditions of technology transfer that determine the intangible benefits attained by technology transfer intermediary agents. Based on an in-depth field study and survey data from multiple stakeholders involved in technology transfer in Singapore, the authors are able to construct a set of cases around more versus less beneficial tech transfer. They then apply fsQCA to analyze the configuration of factors influencing the reverse knowledge flow benefits attained by the technology transfer intermediary agents. They find that the more and the less beneficial transfers had different sets of associated drivers. In particular, intermediary agents are more associated with the higher benefit cases, but have no real association one way or the other with the lower. The same is true for demand readiness and the SME outcomes. Their findings on the mutually reinforcing nature of intermediary agent-recipient benefits have important implications for research and practice. They suggest that studies of research parks and industrial areas (e.g., Armanios et al., 2017; Chen et al., this special issue) should be disaggregated into higher and lower benefit spillover areas, and the role of intermediaries in each examined separately.

In the last section of the paper, we outline an agenda for additional research on the managerial and public policy implication of technology transfer.

3. Research agenda on the managerial and public policy implications of technology transfer at federal/national labs

The papers in this special section of *Research Policy* are based on multiple levels of analysis and address a variety of managerial and policy issues. Consistent with research on open innovation, which similarly reflects a process of knowledge flows across organizational boundaries, we outline a multi-level framework. This framework can be used to identify additional research questions, theoretical perspectives, and research designs, including methodologies and units of analysis. Chesbrough and Bogers (2014) identified the intra-organizational, organizational, inter-organizational, industry, and society levels as providing a potential framing to identify relevant research objects and questions. Generalizing this further, Bogers et al. (2017) suggested combining levels of analysis into broader research categories that would actually bring together perspectives and methods to more comprehensively study to boundary conditions and micro-foundational processes of distributed innovation across organizational boundaries — as consistent with other multi-level perspectives (Bitektine and Haack, 2015; Felin et al., 2015; Gupta et al., 2007).

We have organized the papers in this special issue starting from a micro level and then focusing on the macro level. This multi-level approach is highly useful, but there are still many unanswered research questions, in terms of improving our understanding of technology transfer from federal/national lab and research institutes. In the remainder of this section, we consider a wide set of unanswered research questions at the individual, organizational, regional, and national levels.

We begin at the individual level, where there is a substantial void and a need for more "micro" research. A growing body of research (Balven et al., 2018; Waldman et al., 2021; Choi et al., 2022) shows that organizational and psychological factors play a key role in the commercialization of research at universities and federal labs. These factors pertain to the human dimensions of technology transfer, such as organizational justice, role conflict and identity, diversity equity, and inclusion, championing/leadership, and the ability to collaborate effectively with external partners. Also, from a "microfoundations" perspective (Felin et al., 2015), we need to understand how organizational and institutional attributes shape individual level actions and interactions as well as how individual level action and interactions aggregate up to the higher levels.

More broadly, at the intra-organizational level, researchers should consider the role of individuals, teams, projects and departments on technology transfer from federal/national lab and research institutes. For example, what role do the characteristics of the individual scientists or the teams they work in play in enabling technology transfer, and how does this ultimately aggregate up to organizational level performance? Similarly, what role do managers play in this process, and how may they influence the human research practices and organizational culture that may be more or less favorable to efficient and effective technology transfer from the labs. Also, are leadership and championing behavior on the part of lab managers relevant to technology transfer performance, and if so, how? Are other organizational behavior factors relevant to technology transfer in labs and research institutes? And to turn the question around, it will also be important to consider how technology transfer activity affects individual (scientist) productivity. Also, how does the mobility of research scientists affect scientific productivity and commercialization? Putting this in a broader perspective, another important question would be how effective entrepreneurial initiatives are at these facilities.

At the organizational level, we need more analysis of how technology transfer at federal/national labs and research institutes differs from university technology transfer. At the same time, there may also be fundamental questions regarding how technology transfer has changed the nature of research in federal/national labs. We also need to understand technology transfer strategy formulation and implementation at federal labs and especially, the role of contractors at the GOCO labs.

A very useful aspect of the vast literature on university technology transfer has been the focus on the role of the technology transfer or technology licensing office (TTO or TLO) as an intermediary (Siegel, 2006; Siegel and Wright, 2015a). We need to improve our understanding of TTOs at federal/national labs and public research institutes, which are referred to as offices of research and technology applications or ORTAs. We need more analysis of the organization of ORTAs and their managerial practices. For example, is "bypassing" the ORTA prevalent, and if so, how and why is such "informal" technology transfer accomplished by scientists at these facilities? It is then also relevant to consider how the labs manage the knowledge outflows of such an open innovation process, if they are unable to capture the "spillovers" that derive from this process. This could then have implications for the "business model" of the lab or institutes as the ultimate aim is to create and capture value from the research that is being conducted. By the same token, we can consider knowledge outflow, and ask the question how labs and research institutes formulate and implement technology commercialization strategies.

Going beyond the organizational level to the systems level, there are many important aspects to be examined in the context of technology transfer from federal/national lab and public research institutes. These include policies and program supporting innovation at small firms, which could involve partnership with federal/national labs and public research institutes (Siegel et al., 2003a, 2003b; Siegel and Wessner, 2012). It would also be useful to consider system arrangements that these labs and institutions are part of and their role in the broader ecosystem as the network of interdependent, complementary stakeholders that jointly create value and each capture part of that value (Adner and Kapoor, 2010; Heaton et al., 2019; Ritala et al., 2013). In addition, researchers should explore what role non-university labs play in such an ecosystem, and how it differs from other stakeholders. Also, how do they manage the interfaces with the various external partners in this process? This may then also give rise to a more comprehensive understanding of the emergence and dynamics of innovation ecosystems (Holgersson et al., 2022; Jacobides et al., 2018) as well as to how it relates to other types of ecosystems as well (Acs et al., 2017; Autio and Thomas, 2014: Clarysse et al., 2014). More generally, one may also question how technology transfer has changed the relationships between federal/national labs and industry. And how does research at federal/national labs and research institutes actually affect industrial research? From an innovation system point of view, other questions may also emerge, such as how technology transfer from federal/national labs may change the core missions of the labs, how technology transfer has contributed to changes in the nature of national innovation systems, and how contexts and features of national innovation systems may impact the behavior of technology transfer of federal/national labs?

We also need to consider the sectoral aspect of technology transfer involving federal/national labs, focusing on differences across such fields as the life sciences, engineering, cybersecurity, and of course, energy. There are also other institutional factors that may be specific for this context, also possibly explaining particular performance differences, while the question what is the appropriate intellectual property regime for these institutions is also an important one. What national and regional policies facilitate better technology transfer practice from federal and non-university labs? For example, are there particular policy translation mechanisms that might improve the success of federal and non-university labs tech transfer? Are there others to avoid?

Beyond the above framing in terms of levels of analysis, future research could also consider particular challenges and opportunities related to the operationalization and measurement of relevant constructs in the context of technology transfer from federal/national labs and research institutes. For example, how do we measure patenting output and quality within these organizations? How does these measures compare with private industry and universities? More generally, how should we measure and evaluate technology transfer output and performance for federal/national labs and research institutes? Are there novel, comparative research designs that draw on big data across sectors and countries to allow for a more textured assessment of federal lab innovation and transfer? How can designs and measures capture the bidirectional effects among federal/national lab funding, innovation levels, and enabling policies?

This special section addresses some of these research questions, but there is much more research needed on the managerial and public policy implications of technology transfer at federal/national labs and public research institutes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

Acs, Z.J., Stam, E., Audretsch, D.B., O'Connor, A., 2017. The lineages of the entrepreneurial ecosystem approach. Small Bus. Econ. 49 (1), 1–10.

Adams, J.D., Chiang, E.P., Jensen, J.L., 2002. The influence of federal laboratory R&D on industrial research. Rev. Econ. Stat. 85 (4), 1003–1020.

Adner, R., Kapoor, R., 2010. Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations. Strateg. Manag. J. 31 (3), 306–333.

Armanios, D.E., Eesley, C.E., Li, J., Eisenhardt, K.M., 2017. How entrepreneurs leverage institutional intermediaries in emerging economies to acquire public resources. Strateg. Manag. J. 38 (7), 1373–1390.

Autio, E., Thomas, L.D.W., 2014. Innovation ecosystems: implications for innovation management. In: Dodgson, M., Philips, N., Gann, D.M. (Eds.), The Oxford Handbook of Innovation Management. Oxford University Press, Oxford, pp. 204–288.

Balven, R., Fenters, V., Siegel, D.S., Waldman, D., 2018. Academic entrepreneurship: the roles of identity, motivation, championing, education, work-life balance, and organizational justice. Acad. Manag. Perspect. 32 (1), 21–42. https://doi.org/10.5465/amp.2016.0127.

Bitektine, A., Haack, P., 2015. The "macro" and the "micro" of legitimacy: toward a multilevel theory of the legitimacy process. Acad. Manag. Rev. 40 (1), 49–75.

Bogers, M., Zobel, A.-K., Afuah, A., Almirall, E., Brunswicker, S., Dahlander, L., Frederiksen, L., Gawer, A., Gruber, M., Haefliger, S., Hagedoorn, J., Hilgers, D., Laursen, K., Magnusson, M.G., Majchrzak, A., McCarthy, I.P., Moeslein, K.M., Nambisan, S., Piller, F.T., Radziwon, A., Rossi-Lamastra, C., Sims, J., Ter Wal, A.L.J., 2017. The open innovation research landscape: established perspectives and emerging themes across different levels of analysis. Ind. Innov. 24 (1), 8–40.

Bozeman, B., Crow, M., 1991. Red tape and technology transfer in US government laboratories. J. Technol. Transf. 16, 29–37.

Chesbrough, H., Bogers, M., 2014. Explicating open innovation: clarifying an emerging paradigm for understanding innovation. In: Chesbrough, H., Vanhaverbeke, W., West, J. (Eds.), New Frontiers in Open Innovation. Oxford University Press, Oxford, pp. 3–28.

Choi, H., Yoon, H., Siegel, D.S., Waldman, D.A., Mitchell, M.S., 2022. Assessing differences between university and federal laboratory postdoctoral scientists in technology transfer. Res. Policy 51 (3), 104456.

Choudhry, V., Ponzio, T.A., 2020. Modernizing federal technology transfer metrics. J. Technol. Transfer. 45, 544–559.

Clarysse, B., Wright, M., Bruneel, J., Mahajan, A., 2014. Creating value in ecosystems: crossing the chasm between knowledge and business ecosystems. Res. Policy 43 (7), 1164–1176.

Crow, M., Bozeman, B., 1998. Limited by Design: R&D Laboratories in the U.S. National Innovation System. Columbia University Press, NY, NY.

Dietz, J.S., Bozeman, B., 2005. Academic careers, patents, and productivity: industry experience as scientific and technical human capital. Res. Policy 34, 349–367.

Felin, T., Foss, N.J., Ployhart, R.E., 2015. The microfoundations movement in strategy and organization theory. Acad. Manag. Ann. 9 (1), 575–632.

Feldman, M.P., Link, A.N., Siegel, D.S., 2002. The Economics of Science And Technology: An Overview of Initiatives to Foster Innovation, Entrepreneurship, And Economic Growth. Kluwer Academic Publishers, Boston.

Feller, I., 2022. Assessing the societal impact of publicly funded research. J. Technol. Transf. 47, 632–650.

Grimaldi, R., Kenney, M., Siegel, D.S., Wright, M., 2011. 30 years after Bayh-Dole: reassessing academic entrepreneurship. Res. Policy 40, 1045–1057.

Gupta, A.K., Tesluk, P.E., Taylor, M.S., 2007. Innovation at and across multiple levels of analysis. Organ. Sci. 18 (6), 885–897.

Heaton, S., Siegel, D.S., Teece, D.J., 2019. Universities and innovation ecosystems: a dynamic capabilities perspective. Ind. Corp. Chang. 28 (4), 921–939.

Holgersson, M., Baldwin, C.Y., Chesbrough, H., Bogers, M.L.A.M., 2022. The forces of ecosystem evolution. Calif. Manag. Rev. 64 (3), 5–23.

Jacobides, M.G., Cennamo, C., Gawer, A., 2018. Towards a theory of ecosystems. Strateg. Manag. J. 39 (8), 2255–2276.

Jaffe, A.B., Lerner, J., 2004. Innovation and its Discontents: how our Broken Patent System is Endangering Innovation and Progress, and what to do about it. Princeton University Press, Princeton, NJ.

Jaffe, A.B., Trajtenberg, M., Henderson, R., 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. Q. J. Econ. 108 (3), 577–598.

Jaffe, A.B., Fogarty, M.S., Banks, B.A., 1998. Evidence from patents and patent citations on the impact of NASA and other federal labs on commercial innovation. J. Ind. Econ. 46 (2), 183–205.

Jain, S., George, G., Maltarich, M., 2009. Academics or entrepreneurs? Investigating role identity modification of university scientists involved in commercialization activity. Res. Policy 38 (6), 922–935.

Link, A., Siegel, D.S., Wright, M., 2015. The Chicago Handbook of Technology Transfer And Academic Entrepreneurship. Chicago University Press, Chicago, IL.

Mowery, D.C., Nelson, R.R., Sampat, B.N., 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. Res. Policy 30 (1), 99–119.

<collab>National Academies of Sciences and Medicine (NASEM)</collab>, Engineering, 2021. Advancing Commercialization of Digital Products From Federal Laboratories. The National Academies Press, Washington, DC. https://doi.org/10.17226/26006.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Kitson, M., Krabel, S., Llerena, P., Lissoni, F., Salter, A., Sobrero, M., 2013. Academic engagement and commercialization: a review of the literature on university-industry relations. Res. Policy 42, 423–442.

Perkmann, M., Salandra, R., Tartari, V., McKelvey, M., Hughes, A., 2021. Academic engagement: a review of the literature 2011–2019. Res. Policy 50 (1), 104114. https://doi.org/10.2139/ssrn.3461621.

Price, S.E., Siegel, D.S., 2019. Assessing the role of the federal government in the development of new products, industries, and compa- nies: Case study evidence since World War II. Annals of Science and Technology Policy 3 (4), 348–437. https://doi.org/10.1561/110.00000016.

Rahm, D., Bozeman, B., Crow, M., 1988. Domestic technology transfer and competitiveness: an empirical assessment of roles of university and governmental R&D laboratories. Public Adm. Rev. 48, 969–978.

Ritala, P., Agouridas, V., Assimakopoulos, D., Gies, O., 2013. Value creation and capture mechanisms in innovation ecosystems: a comparative case study. Int. J. Technol. Manag. 63 (3), 244–267.

Siegel, D.S., 2006. Technological Entrepreneurship: Institutions And Agents Involved in University Technology Transfer. Edward Elgar Publishing, Cheltenham, U.K.

Siegel, D.S., Wessner, C., 2012. Universities and the success of entrepreneurial ventures: evidence from the Small Business Innovation Research Program. J. Technol. Transf. 37 (4), 404–415.

Siegel, D.S., Wessner, C., Binks, M., Lockett, A., 2003. Policies promoting innovation in small firms: evidence from the U.S. and U.K. Small Bus. Econ. 20 (2), 121–127.

Siegel, D.S., Waldman, D.A., Link, A.N., 2003. Assessing the impact of organizational practices on the productivity of university technology transfer offices: an exploratory study. Res. Policy 32, 27–48.

Siegel, D.S., Wright, M., 2015a. University technology transfer offices, licensing, and start-ups. In: Link, A., Siegel, D.S., Wright, M. (Eds.), Chicago Handbook of University Technology Transfer And Academic Entrepreneurship. University of Chicago Press, Chicago, IL, pp. 1–40.

Siegel, D.S., Wright, M., 2015b. Academic entrepreneurship: time for a rethink? Br. J. Manag. 26 (4), 582–595.

Sorenson, O., Fleming, L., 2004. Science and the diffusion of knowledge. Res. Policy 33 (10), 1615–1634.

Waldman, D., Balven, R., Vaulont, M., Siegel, D., Rupp, D., 2022. The role of justice perceptions in formal and informal university technology transfer. J. Appl. Psychol. 107 (8), 1397–1413. https://doi.org/10.1037/apl0000944.

Wry, T., Lounsbury, M., Jennings, P.D., 2014. Hybrid vigor: securing venture capital by spanning categories in nanotechnology. Acad. Manag. J. 57 (5), 1309–1333.