A Review of the Literature Related to Investigating the Influence of Development Stage in

University Technology Transfer and the Implications for Public Policy

Malcolm S. Townes

Saint Louis University

Table of Contents

[List of Tables 4](#_Toc41026891)

[List of Figures 5](#_Toc41026892)

[Abstract 6](#_Toc41026893)

[Introduction 7](#_Toc41026894)

[Defining Technology 7](#_Toc41026895)

[Conceptualizing University Technology Transfer 14](#_Toc41026896)

[Characterizing Development Stage 19](#_Toc41026897)

[Approach to Examining the Topic 23](#_Toc41026898)

[The Significance of University Technology Transfer 26](#_Toc41026899)

[Research and Development, Technology, and Social Well-Being 26](#_Toc41026900)

[The Public Interest in University Technology Transfer 30](#_Toc41026901)

[The Role of the Federal Government in University Technology Transfer 31](#_Toc41026902)

[Determinants of Success in University Technology Transfer 35](#_Toc41026903)

[Development Stage as an Understudied Explanatory Factor 39](#_Toc41026904)

[Understanding the Potential Influence of Development Stage 39](#_Toc41026905)

[The Role of Organizations in University Technology Transfer 43](#_Toc41026906)

[Decision Making in an Organizational Context 44](#_Toc41026907)

[Development Stage and Technology Transfer Outcomes 47](#_Toc41026908)

[The Valley of Death in University Technology Transfer 51](#_Toc41026909)

[Development Stage in Federal Technology Transfer Policy 54](#_Toc41026910)

[Conclusion 56](#_Toc41026911)

[References 58](#_Toc41026912)

[Appendix A. Tables and Figures 72](#_Toc41026913)

List of Tables

[Table 1 Federal Obligations to Universities for Research and Development 72](#_Toc41026914)

[Table 2 Federal Policies Related to University Technology Transfer 73](#_Toc41026915)

[Table 3 Determinants of Technology Transfer Outcomes Found in the Literature 77](#_Toc41026916)

[Table 4 NASA Technology Readiness Level Scale 78](#_Toc41026917)

[Table 5 Alternative Readiness Level Scales 79](#_Toc41026918)

List of Figures

[Figure 1 Federal Obligations to Universities for Research and Development, 2000-2019 80](#_Toc41027015)

Abstract

University technology transfer is one of the many areas where the federal government of the United States of America (U.S) has implemented significant goal-oriented actions (i.e., public policy) during the nation’s history, particularly in the last 75 years. U.S. public policy regarding university technology transfer is a topic worthy of serious scholarly study in a public and social policy doctoral program for at least three reasons. It has been a topic of keen interest to the federal government since the latter part of the Second World War. Also, there is a demonstrated link between economic prosperity, national security, and technological innovation. There is also a need to ensure the efficient use of scarce national resources. Moreover, nearly one-third of the federal research and development budget is directed to universities in the United States. When it comes to public policy regarding university technology transfer, the possible role of development stage in university technology transfer outcomes is among the gaps in the knowledge base. The potential role of development stage as an explanatory factor has not been extensively examined in a direct manner. This paper discusses the literature and discourse about the theories, constructs, concepts, operational approaches, and research findings relevant to a proposed study to examine the belief commonly held among technology transfer professionals that the development stage of a technology influences the likelihood that it will be transferred to the private sector for use that benefits the public interest.

Keywords: technology, technology transfer, research and development, development stage, technology readiness level

Introduction

Scholars generally define public policy as some variation of the goal-oriented actions of government (see, e.g., Cairney, 2016; Dye, 1987; Wilson, 2006). University technology transfer is one of the areas where the federal government of the United States of America (U.S.) has implemented significant goal-oriented actions during the nation’s history, particularly in the last 75 years. This is part of what makes university technology transfer an interesting and worthy topic for serious scholarly study in a social and public policy doctoral program.

My interest in technology transfer policy in general, and policy regarding university technology transfer more specifically, is rooted in my professional background. I have firsthand experience with the challenges of technology transfer having worked as a technology transfer professional in university settings for roughly 14 years. I’m convinced it is an area still ripe for scholarly examination, especially as it relates to U.S. public policy. Broadly speaking, this proposed study aims to help practitioners and policymakers better understand why private sector organizations choose not to pursue the acquisition and use of university-created technologies that seem to align with their mission and profit motives even when the organizations appear to have the resources to do so.

Technology transfer is a complex and difficult process. There are many challenges to producing the kinds and levels of outcomes desired from technology transfer efforts in general and university technology transfer activities in specific. One issue that has peaked my interest is the notion common among technology transfer professionals that a technology must progress to a certain minimum stage of development before it can be successfully transferred to the private sector. As such, the proposed study aims to examine the popular belief among technology transfer professionals that the development stage of a technology influences the likelihood that it will be successfully transferred to the private sector for use that benefits the public interest. If an effect is found, this proposed study also seeks to determine the causal mechanism for it.

Defining Technology

To engage in productive discourse about a subject, it’s necessary for everyone to have a clear understanding of the topic of discussion. As such, I begin by defining what I mean by the term “technology.” There is no universally accepted definition of technology, either culturally or in the context of U.S. public policy. In fact, there is significant debate among scholars about the definition of the term. Bozeman (2000) noted the challenge that defining technology and measuring the technology transfer phenomenon posed for researchers. Based on my review of the literature, I conclude that it is entirely appropriate to conceptualize technology in terms of information.

For the purposes of the proposed study, I define technology as culturally-influenced information that social actors use to pursue the objectives of their motivations. This information is embodied in such a manner to enable, hinder, or otherwise control its access and use. This definition is consistent with the observation by Lall (2001) that technology must be embodied in specific items.

This conceptualization of technology can be broadly applied. For example, a journal article is simply information about a scientific phenomenon that is embodied in a periodical format to facilitate is dissemination and accessibility. A patent (under U.S. patent law) is simply information about a manufacture, method, or improvement to a manufacture or method that is embodied in documentation that conforms to guidelines dictated by the government to facilitate its accessibility and use while enabling the patent holder to leverage the coercive powers of the state to prevent others from using the information for a specified period. A trade secret is simply information about something that has inherent economic value that is embodied in documentation, human memory, and protocols to control its accessibility and use while preventing unwanted parties from accessing and using the information. A Clovis point is simply information about using bifacial percussion flaking to create a projectile point that is embodied in physical form to facilitate its use to achieve an end. A smartphone is information about using digital signals and electronic displays to communicate with others that is embodied in physical form to facilitate its use. All these examples represent embodiments of technology and the literature provides support for this conceptualization of technology.

As a construct, it seems that technology is “a bastard child of uncertain parentage” (Schatzberg, 2018, p. 14). Throughout the course of history, the concept of technology has progressively narrowed from the meaning of the original Ancient Greek term *techne*, which is its oldest cognate. As Schatzberg explained, *Techne* referred to the science (i.e., principles and processes) of the useful arts (i.e., branch of learning or human activity). The German concept of *Technik*, which was derived from the concept of *techne* in Ancient Greek, also had a broad meaning in its original use. *Technik* was distinct from the German term *Technologie*, both of which were associated with craft production. *Technik* could take on a broad meaning referring to the rules, procedures, and skills for achieving an objective (i.e., art in the most general sense) or a narrower meaning referring to the physical aspects of commercial enterprise. *Technik* eventually shaped the modern concept of technology in the English language in an unfortunate way. English language scholars mistranslated *Technik*, whose meaning in the German language varied depending on context. Mistranslation of *Technik* contributed significantly to the current confusion in the meaning of technology in the English language (Mitchman & Schatzberg, 2009; Schatzberg 2018).

Currently there are two primary schools of thought among English-speaking scholars regarding the definition of technology (Mitchman & Schatzberg, 2009; Schatzberg, 2018). The instrumental school is the dominant view and conceptualizes technology as tools or implements that serve practical purposes. Proponents of the idea that technology determines culture (i.e., technological determinism) generally espouse this view. Alternatively, the cultural school views technology as the “creative expression of human culture” (Schatzberg, p. 3). Scholars in this camp point to the influence that human culture and agency has in shaping technological change. Both these viewpoints seem to touch on fundamental truths about the nature of technology (Schatzberg) but neither serves as an adequate definition of technology in and of itself. As I see it, these viewpoints are not mutually exclusive. Rather, they are essentially two sides of the same coin.

In the early 1960s a definition of technology emerged in the English language that, although stable over the past several decades, is fairly muddled because it comprises three primary meanings (Schatzberg, 2018). The first meaning is the application of science (i.e., applied science). A second definition is an autonomous body of knowledge, practices, and artifacts (i.e., industrial arts). Finally, a third definition is technique (i.e., instrumental reason). According to Schatzberg, these meanings are incompatible with one another. I would argue that they are also somewhat arbitrary categorizations derived from social machinations.

Feibleman (1961) exemplified the quandary of conceptualizing technology. Feibleman attempted to distinguish between pure science, applied science, technology, and engineering. His approach essentially placed these constructs on a continuum with each one building on the previous one. Feibleman argued that pure science was systematic theoretical and experimental efforts to describe nature and discover laws with no concern for potential application. Applied science was the application of pure science for improving human means and ends. Fiebleman defined technology as improvements of instruments used to extend applied science. This definition conforms to the instrumental reason conceptualization of technology. Fiebleman argued that engineering was technology applied to specific situations. Fiebleman did note that scientific pursuits are not entirely pure science or applied science. Moreover, he observed that both applied science and technology often revealed previously unknown scientific principles and natural laws.

The ambiguity regarding the conceptualization of technology is apparent in studies of technology transfer. Typically, technology transfer studies have not bothered to define the term *technology*. However, they generally seem to conform to the instrumental definition when operationalizing the concept.

Anderson, Daim, & Lavoie (2007); González-Pernía, Kuechle, & Peña-Legazkue (2013); and Markman, Gianiodis & Phan (2005) are representative of studies that often operationalize technology as a disclosure of patentable subject matter to a university or a patent right to a government recognized invention. However, this approach is problematic. It fails to recognize that patentable subject matter is defined by law, which varies across geopolitical borders. What is patentable in one country may not be patentable in another country. Moreover, what is considered patentable subject matter may change over time and thus is not a universal phenomenon. As such, not all technology is patentable.

The ambiguity surrounding the meaning of technology is vexing for both public policy and society in general. For example, there are medications such as anti-depressants, anti-psychotics, and mood stabilizers that are used to treat various mental illnesses. Likewise, the L.E.A.P. (Listen, Empathize, Agree, Partner) method developed by Dr. Xavier Amador through scientific investigation helps mentally ill persons to accept treatment (Amador, 2012). American society tends to view the medications as technology but generally does NOT view the L.E.A.P. method as technology. Moreover, application of the L.E.A.P. method by society does not show up in any technology transfer metric used to measure the transfer of federally-funded research to the private sector for the benefit of the public interest. As such the L.E.A.P. method and other similar examples do not get factored into the policy debate about technology transfer in any significant way. However, if the L.E.A.P. method were patentable subject matter and patented accordingly, society and government metrics would likely recognize it as technology. This seems rather arbitrary and demonstrates a further narrowing of the meaning of technology from applied science and instrumental reason to patentable subject matter, which is evident in current U.S. public policy regarding technology transfer.

Conceptualizing technology in terms of information is not an entirely new idea in the discourse about technology transfer. Williams and Gibson (1990) offered a definition of technology as “information that is put to use” (p. 13). Leonard-Barton (1990) expanded on this by offering that technology was knowledge embodied in an artifact that facilitates the completion of some task. Leonard-Barton further stipulated that such knowledge is technology only when captured in a form that is communicable. Herschbach (1995) acknowledged that technology embodies knowledge and argued that the knowledge embodied in technology only has meaning in the context of human activity. Stoneman (2002) also pointed out that technology has been defined as information or knowledge within the literature and doing so has certain analytical advantages.

The information sciences literature provides a foundation for conceptualizing technology in terms of information. The DIKW (data, information, knowledge, wisdom) hierarchy is the primary paradigm used in information science and knowledge management (Frické, 2019). Conceptualizing technology in terms of information as described in the DIKW hierarchy has at least one advantage. There is general agreement about the elements of the hierarchy, their definitions, and their ordering (Rowley, 2007).

As Frické (2019) explained, each category in the DIKW hieararchy includes the categories below it. Data are symbols that represent the observable properties of objects, events, and environments (i.e., phenomena). Data are true factual statements. By definition, intentionally false statements are not data. Information, in turn, is data that has been processed to answer a query. The difference between data and information is more function than form. Subsequently, knowledge is information that has been transformed into instructions to enable control of a system (i.e., know-that and know-how). Finally, wisdom is knowledge that is applied to achieve an end. Frické argued that the DIKW hierarchy is insufficient and should include document and sign as two additional concepts. This aligns with the notion expressed by Leonard-Barton (1990) that knowledge must be captured in communicable form to be considered technology. Frické also argued that documents are culturally-specific tools for communicating, knowledge, information, and data. This harkens to the cultural school of thought regarding the definition of technology.

Some technology transfer studies have broadened the idea of technology to include academic knowledge (González-Pernía, Kuechle, & Peña-Legazkue, 2013). If we conceptualize technology as information in accordance with the DIKW hierarchy, knowledge encompasses technology. Within the framework of the DIKW, each category includes the categories below it (Frické, 2009). As such, knowledge consists of technology (i.e., information). Technology is used to create knowledge but it is not itself knowledge. Knowledge is often an output of the technology transfer process.

In many respects, technology can be viewed as an impure public good whose consumption is non-rivalrous but excludable. Lall (2001) observed that the information and knowledge aspects of technology have public good characteristics. It is non-rivalrous given that use by one party does not diminish the stock for others. Once a technology is developed, its use by one person generally does not impede its use by another. However, technology may be excludable depending on its embodiment or it can be made excludable by conferring property rights in the form of intellectual property (i.e., patents, copyrights, and trade secrets) that can be enforced using the coercive powers of the state.

Conceptualizing University Technology Transfer

Of principal concern for this proposed investigation is university technology transfer in the United States. My review of the literature leads to me do define university technology transfer as the conveyance of technology derived from research and development (R&D) conducted by U.S. universities to private and non-profit sector actors for use that benefits the public interest. On the surface, the concept of technology transfer seems rather straightforward. However, if one takes the time to consider what it means to transfer technology, the challenges become obvious.

Like technology, there is no universally accepted definition of the general concept of technology transfer. Most studies of the subject fail to explicitly define term. The definition of technology transfer seems to vary depending on the approach to the topic. For example, in their investigation of the effects of international technology transfer on welfare under the conditions of Bertrand and Cournot competition, Kuo, Lin, and Peng (2016) defined technology transfer as “the process of transferring a new technology from a firm in one country to a firm in another country” (p. 214). The term *commercialization* is often used as a synonym for technology transfer; however, it is generally used in the context of technology transfer endeavors driven by profit motives (see, e.g., Gulbrandsen & Rasmussen, 2012; Mercelis, Galvez-Behar & Guagnini, 2017).

Conceptualizing technology as information may help bring some clarity to the definition of technology transfer. At the most basic level, one may think of technology transfer as simply the conveyance of information from the possession of one social actor to the possession of another social actor for the purpose of applying the information in a setting in which it has not previously been applied. This conveyance may occur in various contexts such as between affiliated or unaffiliated social actors and across geopolitical borders. It may occur in various manners such as formally or informally. It may occur through various mechanisms such as fee-based patent licenses, non-fee creative commons licenses, product sales, service delivery, or collaborative work arrangements. It may also occur through various methods such as sanctioned or illicit. Moreover, social actors may engage in technology transfer to achieve a variety of objectives such as generating financial gain, increasing competitive advantage in a commercial market, increasing the standard of living within a country, facilitating broader economic development within a geopolitical border, or simply developing culture and cultural structures. More specifically, university technology transfer is conceptualized, for the purposes of the proposed study, as information created by university researchers through systematic methods and practices of inquiry that is knowingly and willingly conveyed to third party actors who intend to apply the information in a setting in which it has not previously been applied.

The conceptualization and operationalization of university technology transfer seems to have been troublesome for scholarly research on the subject. Kundu, Bhar, and Pandurangan (2015), for example, defined technology transfer as “the process by which technology, knowledge, and information developed in one organization for one purpose is applied and utilized by another area in another organization, for another purpose” (p. 70). This definition seems somewhat labored. Kundu, Bhar, and Pandurangan seem to have been striving for a definition that comprehensively captures the technology transfer phenomenon but their definition falls short of the goal.

Speser (2012) defined technology transfer as “the transfer of technology from one person to another across organizational lines” (p. xxiii). This definition seems somewhat circular. It fails to clarify what is means for a technology to be “transferred.” Moreover, the definition of technology that Speser uses in her model is narrow. According to Speser, technologies are ideas that can be embodied in such a form that their creators can secure property rights and rely on the coercive powers of the state to enforce those rights.

In defining and operationalizing technology transfer, it is important to distinguish between it and the closely related phenomenon of technology diffusion. Technological diffusion is concerned with the dissemination of a technology throughout an industry, economy, or society after first incorporation whereas technology transfer has more to do with the introduction and first incorporation of a technology (Stoneman, 2002).

Generally, studies of the topic seem to conflate technology transfer with the mechanisms for achieving it. Moreover, most research studies of university technology transfer appear to select indicators and measures more for convenience rather than to maximize construct validity. Licensing and new venture formation are typically used as indicators of technology transfer. Research collaborations and faculty consulting agreements, although discussed in the literature, are used far less frequently. Executed patent licenses, established new business entities, and executed sponsored research agreements have also been used as proxies for technology transfer (see, e.g., González-Pernía, Kuechle, & Peña-Legazkue, 2013; Hallam, Wurth & Mancha, 2014; Markman, Gianiodis & Phan, 2009; Tseng & Raudensky, 2014). Each of these approaches has its shortcomings.

Several scholars have commented on the limitations of typical conceptualizations of technology transfer. Fraser (2010) described the trend in approaches for measuring technology transfer success as having transitioned from input metrics to output indicators to outcome and impact measures, the last of which technology transfer practitioners believe are more appropriate. Carlsson and Fridh (2002) concluded that university technology transfer outcomes are only partially reflected in measures of income generation and new business venture formation. Herzog and Wasden (2013) specifically recommended against using licensing revenue as the primary measure of technology transfer success because it constitutes only a portion of the outcome of technology transfer efforts. Fraser also offered several outcome and impact phenomena to which technology transfer contributed including the economic impact on the area in immediate proximity to the institution, number of lives saved, improvements in the lives of patients, and increases in competitiveness. However, each of these present their own measurement challenges.

While the link between such outcomes and technology transfer activity is not difficult to grasp intellectually, measuring them and establishing a causal relationship often proves elusive. Fraser (2010) mentioned several notable examples of new approaches to measuring technology transfer success including academic impact, economic impact, financial impact, and societal impact metrics created by the University-Industry Liaison Office at the University of British Columbia in Canada and a macroeconomic study conducted on behalf of the Biotechnology Industry Organization.

The methods used in many studies to operationalize university technology transfer present the risk of incorrectly categorizing or double counting activities depending on how the measures are used. For example, a patent license is often associated with the formation of a university spinout company (i.e., a new business venture to commercialize technology developed at a university). In such situations, using both measures would essentially double count a single instance of technology transfer. Another example is sponsored research, which may not be related to technology previously developed at the university. As such, it may be misleading to consider all sponsored research as instances of successful university technology transfer. Additionally, these measures of technology transfer don’t accommodate instances that are not commercial transactions in nature. Theoretically, technology transfer can occur in the absence of a financial transaction.

Generally speaking, technology transfer can also be thought of as an impure public good as well as a merit good. The marginal cost of an additional actor pursuing the application of a technology is often negligible. Thus, technology transfer can be considered non-rivalrous. However, technology transfer can be made excludable through legal mechanisms such as options and licenses for intellectual property. A merit good satisfies a public want and could be provided by the market because it can be made excludable but is under-consumed simply because of consumer choice, not necessarily because of market failure. As such, the government intervenes to force public consumption to correct individual choice rather than a market failure (Desmarais-Tremblay, 2017; Musgrave, 1959). Technology transfer seems to satisfy the definition of a merit good. It produces societal, ecological, and economic benefits (Lidecap, 2009; Link & Scott, 2019). American society has decided that technology transfer is needed as is evident by the decisions of the nation’s elected leaders to implement public policy to encourage and facilitate it.

Technology transfer in general has been the subject of serious scholarly research since at least the 1960s. Schrier (1964) is one of the earliest peer-reviewed published works to explicitly address the subject. The paper was inspired by Schrier’s participation in The Engineering Foundation Research Conference, which was assembled in August of 1963 to explore the theme of “Technology and the Civilian Economy.” One of the most discussed issues was the transfer of technologies derived from scientific research and development to industry. Schrier reported that technology transfer was a controversial subject at the time. Those focused on the topic found developing adequate solutions to the challenges of technology transfer rather elusive. Schrier also pointed out that there was a large stock of unexploited technology derived from federally-funded research and development. Nearly 60 years later, this statement remains true. The proposed study aims to answer the question of why private sector organizations do not pursue the acquisition and use of technologies derived from research and development conducted at universities in the United States that seem to align with their missions and profit motives even when the organizations appear to have the resources to do so?

Characterizing Development Stage

The conceptualization of development stage is not as challenging as that of technology and technology transfer. The common, everyday use of the words in the term are quite relevant. In common vernacular, *development* is a noun that simply means “the process in which someone or something grows or changes and becomes more advanced” or “the process of developing something new” (Development, 2020). There are two common meanings of the transitive verb *develop* that are relevant. The first is “to (cause something to) grow or change into a more advanced, larger, or stronger form.” The other is “to invent something or bring something into existence” (Develop, 2020). A relevant and appropriate meaning of the noun *stage* is “a part of an activity or period of development” (Stage, 2020). For the purposes of the proposed study, I conceptualize development stage as the characterization of the state of creation of a technology at a given point in time. However, operationalization of development stage is more of a challenge for the proposed study than is conceptualization.

Development stage must capture more than just the technical development of a technology. It also needs to capture economics-related performance (Mankins, 2009). As Stokes (1997) noted, the trajectory of technology is not just dictated by technical considerations. Market considerations also greatly influence the development and adoption of technology. There are two primary types of risk that development stage needs to describe. Blank and Dorf (2012) noted the difference between invention risk (i.e., technical risk) and market risk. Invention risk is possibility that the technology cannot be made to work as desired. Market risk is the possibility that end users will not adopt the technology even if it can be made to work as desired. Speser (2006) also discussed these differences in kinds of risk and included firm-specific risk as a third type. Speser argued that one could not control market risk but the lean startup methodology that has gained widespread acceptance among entrepreneurship practitioners and support organizations has demonstrated that this is not the case.

Success in university technology transfer requires managing both types of risk. Approaches that address market risk without consideration of invention risk will fail because they unduly raise hopes and make empty promises. They simply won’t deliver. Those that address invention risk without consideration of market risk will fail in the market for lack of demand. No one will care. In both cases, the final result is an unsuccessful attempt at technology transfer.

Technology readiness level (TRL) is the predominant approach to specifying development stage found in the literature. The National Aeronautics and Space Administration (NASA) develop the concept of TRLs in the mid-1970s as a discipline-agnostic, technology-independent method to assess and communicate the maturity of new technologies (Mankins, 2009). This provided a way for the agency to determine which technologies were appropriate for consideration and inclusion in vehicles and systems for space missions. Mr. Stan Sadin of the Office of Aeronautics and Space Technology is credited with devising the original TRL scale, which consisted of seven levels, each with a brief one-line definition (Banke, 2010; Mankins, 2009). In 1995, NASA further articulated and refined comprehensive definitions for a TRL scale (Mankins, 1995; Mankins, 2009). This resulted in a nine level TRL scale that NASA currently uses (Table 4). Since then various government agencies and private sector organizations have adopted the TRL scale (Mankins, 2009). In fact, the U.S. Congress mandated the use of TRLs in the NASA and Department of Defense (DoD) programs (Nolte & Kruse, 2011).

The use of the TRL scale to denote development stage has also taken hold in the field of technology transfer. Spearman (2013) specifically used the concept of TRLs to describe development stage and the point where it becomes more difficult to advance the technology to where it is useful and can be transitioned to the private sector for commercialization. Speser (2006) also used the TRL scale as an indication of the maturity of a technology in the technology transfer process.

The TRL scale is not without its shortcomings. Olechowski, Eppinger, Tomascheck, and Joglekar (2020) investigated the challenges associated with using the TRL scale in practice. Using an exploratory sequential mixed methods design consisting of qualitative semi-structured interviews and an online survey that included a best-worst scaling (BWS) experiment, they identified 15 challenges that practitioners face when using the TRL scale. The participants in the study were predominantly private-sector professionals from the aerospace, defense and government, and technology industries who had roles related to hardware development and advanced systems engineering. Olechowski, Eppinger, Tomascheck, and Joglekar found that challenges encountered by practitioners were related to either system complexity, planning and review, or assessment validity. System complexity challenges pertained to incorporating new technologies into highly complex systems. Challenges related to planning and review concerned the integration of TRL assessment outputs with existing organizational processes, particularly those related to planning, review, and decision making. Assessment validity challenges had to do with the reliability and repeatability of assessments using the TRL scale. One of the most critical challenges identified was that TRL assessments do not necessarily provide insight into system readiness. Effective university technology transfer is likely to entail systems level endeavors. Olechowski, Eppinger, Tomascheck, and Joglekar speculated that addressing these challenges could substantially improve decisions practices and outcomes in complex engineering undertakings.

It’s not surprising that the private-sector practitioners would encounter challenges using the TRL scale. As an agency of the federal government, NASA developed the TRL scale in the context of public sector applications. The public sector is not motivated by economic profit in the same way as the private sector. The TRL scale focuses on technical risk (i.e., invention risk). As such, it likely does not capture important economic factors relevant to technology development that are significant factors for private sector decisions regarding university technology transfer opportunities.

Some scholars have proposed alternative metrics to address shortcomings of the TRL scale as well as alternate scales that express the notion of development stage in various contexts (Table 5). Most of these scales seem to focus on technical risk. Mankins (1998) introduced the research and development degree of difficulty scale as a complement to the TRL scale to indicate the amount of difficulty expected in maturing a technology. Bohn (1994) offered an eight-level ordinal scale for measuring and evaluating the amount of knowledge an organization possesses about its production processes. In fact, so many alternatives and variants of the TRL scale have been offered, introduced, or adapted for various situations that readiness level proliferation has become a problem in the public sector (Nolte & Kruse, 2011).

Approach to Examining the Topic

Successfully completing any public and social policy research study requires one to clearly understand and define what is being investigated and the objectives. To do otherwise is tantamount to pursuing a fool’s errand, much like the proverbial snipe hunt. Such clarity of mission includes a clear understanding of the need for the public policy being investigated in addition to definitional and operational understanding of concepts. As such, in addition to definitional and operational questions – such as how does one define technology and at what point is a technology considered to be transferred – among the first questions that must be answered to pursue the proposed line of research are (1) why is technology derived from research and development important for social well-being?, (2) what is the public interest in university technology transfer?, (3) why is it appropriate for the federal government to intervene in university technology transfer?, (4) what should be the role of the government in university technology transfer?, and (5) what is currently known about the determinants of success in university technology transfer?

Answers to these questions will inform several key decisions regarding the research design of the proposed study. A review of the literature will provide answers to these questions and others, which will help better isolate the research query to produce original scholarly research that will significantly contribute to the body of knowledge relevant to university technology transfer policy. I expect to have roughly three (3) years to complete the proposed research.

As I see it, understanding university technology transfer as a phenomenon is primarily an exercise in understanding government intervention and organizational decision making. As such, the literature on public sector economics, organization theory and behavior, and decision theory provides the theoretical and conceptual framework for the proposed study.

Public sector economics provides the necessary perspective to understand the implications of conceiving technology and technology transfer as impure public goods and merit goods. Public sector economics is concerned with four primary questions. First, what goods should society produce? Second, how should society produce these goods? Third, for who’s benefit should society produce these goods? And finally, by what standard should society answer the previous three questions (Stiglitz & Rosengard, 2015, p. 13)? The answer to the primary research question of the proposed study has implications principally for the second and fourth questions.

Social actors, whether individuals acting on their own behalf or in the context of membership in an organization, are purpose-driven and act based on motivations (Herzberg, Mausner, & Snyderman, 1959; Maslow, 1943). They use their available resources to achieve objectives aligned with those purposes, whether their motivation is simple survival, financial gain, self-actualization, or creative expression. Technology is one such key resource that social actors use to pursue the objectives of their motivations.

Under the current approach to university technology transfer, private sector organizations are presumed to be the consumers of university-created technologies. This includes entrepreneurs who will need to develop organizations to successfully leverage the technologies they acquire to create value and build wealth. Current federal policy regarding university technology transfer depends on the participation of private sector organizations. In the absence of private sector organizations participating in the process, university technology transfer does not occur. As such, how organizations function needs to be considered when crafting public policy regarding university technology transfer.

Organization theory and behavior provides the perspective to understand how organizations function in the context of university technology transfer. Private sector organizations pursue actions to improve performance, facilitate success, and ensure their survival (Pfeffer, 1997). Organization theory and behavior examines these issues and thus can provide insight.

Before any action can be taken, there must be a decision to act. Thus, private sector organizations must make affirmative decisions to undertake technology transfer initiatives and coordinate their internal activities to carry them out. However, organizational decision making is different than individual decision making. Decision making in an organizational context involves interactions among individuals and groups. Thus, organizational decision making is a social phenomenon. This implies that university technology transfer is also a social phenomenon and the tools of social science should prove useful in generating insights that will better inform public policy regarding the topic.

Because the discourse related to the proposed study draws upon various fields and is therefore interdisciplinary, I have organized this literature review thematically. I begin by discussing the public interest in research and development and the technology it produces. I then explore the public interest in the technology transfer in general and university technology transfer in specific. Next, I examine the appropriate role of government in university technology transfer. I follow this with a summary of the determinants of success in university technology transfer and the gaps in knowledge about explanatory factors. I then turn my attention to the perspective of organization theory and behavior and decision. I discuss the literature that provides insight about organizations in the context of university technology transfer and how organizations make decisions about acquiring and using technologies created by universities. I follow this by examining the discourse about development stage as an explanatory factor in university technology transfer outcomes. This includes consideration of the literature about the “valley of death” in university technology transfer. I subsequently review literature that helps to understand the role of development stage in federal policy regarding university technology transfer. I conclude by suggesting next steps in pursuing the proposed line of research.

The Significance of University Technology Transfer

I begin this review of the related literature by examining the discourse about the significance of university technology transfer. Just because a topic is interesting or a question has not previously been investigated is not sufficient reason to pursue a line of research in and of itself. The issue should be of such importance that it affects the decisions and actions of academics, practitioners, and policymakers as well as the quality of life for individual lay persons. As my review of the literature demonstrates, university technology transfer satisfies this criterion.

Research and Development, Technology, and Social Well-Being

Technology transfer has been the subject of keen interest to the federal government since the latter part of the Second World War when President Franklin Delano Roosevelt requested recommendations for leveraging the capabilities that the Office of Scientific Research and Development (OSRD) cultivated during the war effort. President Roosevelt sought to leverage these capabilities for generating scientific discoveries and developing new technologies to improve the health, standard of living, and economic well-being of Americans (Bush, 1945).

Following the Second World War, federal public policy was that any inventions resulting from federally-funded research belonged the federal government. The federal government would only license these inventions on a non-exclusive basis. The administrations of Presidents John F. Kennedy, Lyndon B. Johnson, and Richard M. Nixon all concluded that this policy potentially negated any economic incentives the private sector might have to commercialize technologies derived from federally-funded research. Consequently, all three administrations issued Presidential policy memoranda to create limited exceptions to the rule (Stevens, 2004).

The modern era of university technology transfer began with the enactment of the Bayh-Dole Act of 1980, which incentivized universities to effectuate the transfer of technologies to the private sector to benefit the public interest by allowing U.S. universities to take assignment of patents for inventions resulting from the federally-funded research and development conducted at their institutions. In signing this legislation, President James E. Carter nudged the nation towards a Jeffersonian philosophy about technology transfer. This approach held that the key to successful technology transfer was the private sector. Government could best support technology transfer by staying out of the way and eliminating impediments that prevented the private sector from making use of the technologies (Stevens, 2004). President Ronald W. Reagan subsequently threw his support behind this approach in a presidential memorandum on government patent policy (Reagan, 1983; Stevens, 2004).

The irony the Bayh-Dole act was diametrically opposite to the position of the Carter Administration and President Carter could have stopped enactment of the legislation with a pocket veto in the waning days of his administration. The Carter Administration was more aligned with a Hamiltonian philosophy believing that a strong central government should actively manage technology transfer activities. Moreover, it supported the notion that large companies primarily drove U.S. economic development. However, President Carter capitulated to political pressure and signed the Bayh-Dole Act (Stevens, 2004).

President George H. W. Bush also professed support for technology transfer. In remarks to the National Technology Initiative Conference, President Bush expressed a desire for technology transfer to be “not just a concept, but a job-producing reality” (Bush, 1992, p. 1645). He emphasized that successful technology transfer depended on the private sector. In facilitating technology transfer, President Bush indicated a strong preference for market-like mechanisms that enabled the private sector to identify and commercialize promising technologies. Moreover, he questioned the wisdom of industrial policy and the ability of the federal government “to pick the right investments…, to control the resources, to determine which particular product and process will be favored” (p. 1642).

In his statement on signing the Technology Transfer Commercialization Act of 2000, President Clinton asserted the administration’s desire to improve technology transfer outcomes as a matter of public policy. He observed that technology transfer serves as a source of competitive advantage for private sector businesses. He stated the act would help ensure that the benefits of federally-funded research are translated into new products that benefit the American public (Clinton, 2000).

Since then subsequent administrations have identified the transfer of technology derived from federally-funded research and development to the private sector as a key objective. The President’s Management Agenda (PMA) for the administration of President George W. Bush specifically listed technology transfer as a priority (OMB, 2002). While the administration of President Barack H. Obama did not issue PMAs, President Obama did issue a presidential memorandum on October 28, 2011 that explicitly focused on technology transfer and commercialization of federal research. In the policy section of this memorandum, he referenced the Startup America initiative which has as one of its objectives “increasing the rate of technology transfer and the economic and societal impact from Federal research and development (R&D) investments” (Daily Comp. Pres. Doc., 2011-October-28). The PMA for the Donald J. Trump administration also identified technology transfer as an important national objective (Office of Management and Budget [OMB], 2018).

Technology transfer policy is also important because of the link between national economic prosperity and technological innovation. Solow (1957) estimated that roughly 88 percent of the total increase in real Gross National Product (GNP) was attributable to technological progress. Consequently, it’s important for the nation to maintain its technological prowess to continue the way of life that citizens and residents of the country have come to expect. It’s logical to conclude that effective university technology transfer policy plays an important role in achieving this objective.

From a more pragmatic standpoint, the efficient use of scarce national resources makes technology transfer policy an important issue for examination. Although total R&D spending represented just roughly 3.4 percent of the federal government’s $3.9 trillion in total federal outlays (Congressional Budget Office [CBO], 2018), it is not a triviality considering that the amount is greater than the gross domestic product (GDP) of at least 110 countries (United Nations [UN], 2017). Moreover, the U.S. budget deficit for fiscal 2019 was more than $100 billion (U.S. Department of the Treasury, 2018a) and the U.S. total public debt as of October 31, 2018 was more than $21.7 trillion (U.S. Department of the Treasury, 2018b).

Under these circumstances, making every dollar count is imperative. Schrier (1964) pointed out that there was a large stock of unexploited technology derived from federal research and development, which remains to this day. There are other important problems of national interest to which the government could direct monies currently being spent on research and development such as road repairs, alleviating hunger, and addressing issues with inequity in the court system. Federal research and development expenditures are equivalent to roughly 20 percent of the federal budget deficit and exceed federal spending on transportation, the Supplemental Nutrition Assistance Program (SNAP), and law courts (U.S. Spending, n.d.). As such, it’s important to ensure that technology transfer policy in general and university technology transfer policy in specific are as optimized as possible.

The Public Interest in University Technology Transfer

As stated above, university technology transfer can be broadly defined as the conveyance of technologies derived from research and development conducted at U.S. research universities to the private sector to benefit the public interest. Most of the funding for this research and development activity comes from the federal government. In fiscal year 2017, the U.S. federal budget for total research and development was greater than $132.7 billion (American Association for the Advancement of Science [AAAS], 2018a), of which about $40.94 billion (roughly 31 percent) went to universities (American Association for the Advancement of Science [AAAS], 2018b). Since 2000, federal obligations to universities for research and development have generally been increasing (Table 1 and Figure 1).

As with many public goods and merit goods, measuring the social value of university technology transfer can be difficult. This challenge is particularly pertinent because it has such a significant influence on public policy decisions. University technology transfer produces social, ecological, and economic benefits. However, the assessments of the social and ecological benefits of university technology transfer are scant and often conducted in an ad hoc manner (Lidecap, 2009). As Lidecap observed, current methods for assessing the value of university technology transfer primarily rely on metrics of tangible directly observable outputs, such as patent awards and patent licenses executed. But such approaches have shortcomings. As Lidecap noted, they do not capture other outputs and outcomes that might be in the public interest such spillover effects, human capital development, and increases in quality of life. Moreover, as Link, Siegel, and Wright (2015) pointed out, technology transfer may occur informally. Such informal instances simply are not captured in the metrics currently used to examine technology transfer.

Link and Scott (2019) argued that social welfare increases when federal laboratories (and by logical extension universities) can provide technology more efficiently than private sector firms can create for themselves. They argued that the increase in social welfare results from increased profits for private sector firms and lower prices for consumers. However, this assumes that all technologies transferred are cost-reducing and that private sector firms will in fact pass along cost savings derived from technology adoption to consumers. This may not necessarily be the case.

The Role of the Federal Government in University Technology Transfer

The need for government intervention in technology transfer came to the forefront as early as the latter part of the Second World War. Bush (1945) presented a normative argument in support of government participation in university technology transfer. He also noted that members of the committee on science and the public welfare that advised him during the preparation of his report either strongly believed or were sympathetic to the idea that government should encourage the formation of “new scientific enterprises” (p. 109) but were not able to agree on solutions for achieving this end.

Kochenkova, Grimaldi, and Munari (2016) examined the topic of knowledge transfer from academia to the private sector. They used the terms knowledge transfer and technology transfer interchangeably. Kochenkova, Grimaldi, and Munari concluded that the main justification found in the economic literature for government intervention in university technology transfer (or knowledge transfer as they sometimes called it) was market inefficiencies and systemic failures such as communication difficulties and differences in priorities, goals, and objectives of actors in the transfer process.

Some researchers have characterized university technology transfer as a market for innovation in which U.S. universities act as suppliers of technologies and private sector businesses act as consumers (see, e.g., Markman, Gionidis, & Phan, 2009). If this is the case, the market for university-created technologies seems to suffer from various forms of market failure. Scientific knowledge has a public good nature but measuring its societal benefits is rather difficult (Heisey & Adelman, 2011).

A market is a system in which one or more owners of property rights engage in the transfer of those property rights with one or more buyers in a process guided by price signals (Kohler, 1992, p. 38). Market failures are conditions in which markets are not Pareto efficient and provide a rationale for government intervention (Stiglitz & Rosengard, 2015, p. 83). Pareto efficiency only occurs when there is a sufficiently large number of suppliers and buyers each believing that it cannot influence prices for market goods. Failure of competition results when this condition is not satisfied. University technology transfer appears to suffer from this situation.

Although there are many universities willing to engage in the exchange of property rights for technologies and there are numerous private sector companies willing to acquire technologies under the right circumstances, university technology transfer resembles monopolistic competition. For any given technology, there generally are few, if any, direct substitutes. Owners of technologies that can be patented, which is the predominate focus of university technology transfer offices, are granted the right to prevent competitors from practicing the inventions (i.e., technologies) for a limited period. Rarely is it the case that multiple patented technologies each addressing the same application are competing with one another at the same time for an acquirer’s consideration. Moreover, price signals are not the mechanism that guide potential exchanges. Both universities and private sector companies believe they can affect the price of an exchange and thus often engage in extensive negotiations to effectuate transfers of technologies.

The conditions in which university technology transfer occurs also appear to produce incomplete markets. There are information asymmetries in the university technology transfer process. Generally, a private sector company is less informed than the university about the nature of the technical risks associated with deriving utility from any given technology it is considering. Universities are generally less informed than a given private sector company about the nature of the market risks associated with successfully using a technology in any given application. Additionally, there are extensive transaction costs associated with acquiring and utilizing a technology.

Given that university technology transfer appears to suffer from at least two types of market failure, it seems reasonable to conclude that the government must intervene in some manner to increase the percentage of technologies derived from federally-funded research and development conducted by U.S. universities that are transferred to the private sector to benefit the public interest. Federal public policy related to university technology transfer has increased over the years but has not yet produced the desired outcomes.

Bush (1945) pushed for the creation of a new federal agency to coordinate the government’s efforts to leverage the research and development capabilities the nation developed during the Second World War to create new technologies to improve the health, standard of living, and economic well-being of Americans. Funding research and development to be conducted by universities in the United States was a significant component of this effort. Moreover, Bush argued that the functions, powers, and duties of this new agency, which would eventually become the National Science Foundation (NSF), should include improving the transition of research discoveries to practical applications by the private sector.

There are at least 14 federal laws and executive directives that form public policy regarding university technology transfer (Table 2). These policies seem to focus predominantly on the problems of incomplete information. The Bayh-Dole Act of 1980 allowed universities to take assignment of patents for inventions derived from federally-funded research and development. The premise behind the law was that providing universities with property rights to inventions would create an economic incentive for universities to effectuate their transfer, primarily through licensing, to private sector organizations for use that benefits the public interest.

The core paradigm that provides the framework for federal funding of research and development and guides policy regarding technology transfer is based on a linear model relating science and technology. Bush (1945) used this paradigm as the basis for recommendations that established the current structure for federal funding of research and development conducted by U.S. universities and subsequent technology transfer activities. Stokes (1997) examined this paradigm and argued, based on experience and reasoned analysis, that it is fundamentally flawed. This paradigm posits that pure basic research is the fountain from which all technological progress springs forth. As Stokes explained, in the dynamic linear variant of the paradigm, basic research leads to applied research which gives way to development which subsequently results in production and operations technologies. Stokes demonstrated that this one-dimensional linear model is both inadequate and inaccurate in describing reality.

Determinants of Success in University Technology Transfer

Researchers have used various frameworks and approaches to examine the underlying determinants of success in university technology transfer. Bozeman (2000) noted that technology transfer studies at the time were heavily focused on evaluation research. This supported the development of theories to explain technology transfer as a phenomenon because evaluation research typically requires empirical analysis. However, evaluation research usually focuses on the interests of the sponsoring institutions rather than theoretical considerations. Bozeman championed the contingent effectiveness model in studies of technology transfer. A major premise of this model is that effective technology transfer has multiple meanings.

Anatan (2015) identified transaction cost economic theory, the resource-based view, and the knowledge-based view as three major theories in the literature used to explain university to industry knowledge transfer in the context of alliances. Anatan proposed institutional theory as an alternative framework for explaining factors that affect the university to industry knowledge transfer process. Anatan argued that external environmental forces pressure organizations to form alliances to enable university to industry knowledge transfer.

Various forms of multiple regression analysis are commonly used approaches to study technology transfer found in the literature. Annual survey data collected by the Association for University Technology Managers (AUTM) from its member institutions is a popular data source for such studies. Arshadi and George (2008) used hierarchical regression analysis on data from AUTM member institutions to identify institutional factors associated with successful university technology transfer. Carlsson and Fridh (2002) also conducted multiple regression analysis using survey data from 170 universities in the United States that was collected by AUTM to identify factors associated with successful university technology transfer. Heisey and Adelman (2011) combined AUTM data with research and development expenditure data from the Survey of Research and Development Expenditures at University and Colleges for their multiple regression analysis of university technology transfer. However, it’s reasonable to assume that all the factors that potentially affect success in university technology transfer don’t necessarily show up in such data.

Markman, Gianiodis, & Phan (2009) used hierarchical multiple regression analysis to study the role of research universities in the United States as suppliers in a market for innovation. The authors used reasoned analysis based on agency theory and real options theory to argue that technology transfer outcomes as measured by licensing revenue and startup creation are a function of licensing strategy, the degree of autonomy of the technology transfer unit, and the incentives provided to various actors in the technology transfer process. They controlled for the age and size of the technology transfer unit, the quality of the faculty, the existence of a business incubator within the institution, and whether the university was public or private. The study used data from surveys administered by AUTM as well as telephone interviews and content analysis of the websites of licensing units conducted by the authors. Markman, Gianiodis, and Phan found that there was a statistically significant positive association between licensing revenue and the size of the technology transfer unit, faculty quality, and financial incentives for departments. There was a statistically significant negative association between licensing revenue and use of licensing agreements strategy, use of sponsored research strategy, low-autonomy of the technology transfer unit, and financial incentives for faculty inventors. The model only explained about 13 percent of the value of the dependent variable. Using startup creation as the dependent variable, the authors found statistically significant positive relationships with public institutions, faculty quality, high-autonomy of the technology transfer unit, and salary of the staff of the technology transfer units. There were statistically significant negative associations with the age of the technology transfer unit and financial incentives for faculty inventors. This model explained just 7 percent of the value of the dependent variable. The authors pointed out that licensing and startup creation are only two of many methods that knowledge (i.e., technology) is disseminated by universities.

Experimental designs are not very prevalent in studies of university technology transfer. Dolmans, Shane, Jankowski, Reymen, & Romme (2016) is one of the few studies I encountered that used such an approach. They conducted a randomized experiment with a 2x1 between-subjects design using technology licensing officers at Carnegie I rated research universities in the United States as subjects. The focus of this study was to understand how inventor appearance influenced the decisions of university technology licensing professionals regarding which technologies to pursue transfer to the private sector. The authors found a statistically significant positive association between inventor appearance and decisions to pursue technology transfer.

Studies of technology transfer in general, and university technology transfer in specific, seem to have mostly focused on factors exogeneous to the technology transfer process (Table 3). Arshadi and George (2008) found that the number of licenses and options executed by universities was positively correlated with the number of licensing agents and cumulative research expenditures for the institution. However, they found no association between those factors and the number of licenses and options and the amount of licensing income generated. The adjusted R-squared was 66 percent for their model that used licenses and options as the dependent variable and 86 percent for their model that used research expenditures as the dependent variable. However, the authors did not address causality in their analysis. Marion, Dunlap, and Friar (2015) discussed several determinants of successful university technology transfer executed through academic entrepreneurship. Again, most of the determinants examined were related to organizational structure and were exogenous to the technology transfer process itself.

Heisey and Aleman (2011) concluded that there was a statistically significant association between certain characteristics of the university technology transfer offices and the amount of revenue generated from licensing university-created technologies. They found a weak relationship between the aggregate amount of short-term research expenditures for universities and the amount of licensing revenue generated.

Other studies have also focused on the relationship between institutional characteristics and technology transfer outcomes (see, e.g., González-Pernía, Kuechle, & Peña-Legazkue, 2013; Kim, Daim, & Anderson, 2009; Markman, Gianiodis & Phan, 2009). These studies found statistically significant associations with various institutional characteristics including staff levels, years of operation, technology portfolio size, office autonomy, university specialization, and entrepreneurship-related infrastructure. York and Ahn (2012) used a comparative case study method to identify factors associated with university technology transfer success. Most of the determinants they identified were related to organizational structure. However, using hierarchical regression analysis Wu, Welch, and Huang (2015) found that individual factors, particularly researcher attitude toward technology transfer and their involvement post-disclosure, were more strongly associated with success than institutional factors. Like most studies of university technology transfer, Wu, Welch, and Huang operationalized technology transfer success as the execution of a license for a patent assigned to the university.

Very few research studies focused on factors that are more endogenous to the technology transfer process. Kundu, Bhar, and Pandurangan (2015) examined intrinsic factors of technology transfer in the context of economic development. However, the factors they described are intrinsic primarily relative to the individual actors and not necessarily the technology transfer process.

Development Stage as an Understudied Explanatory Factor

In my review of the literature, I found only one study that specifically investigated the association between development stage and university technology transfer. Munteanu (2012) examined whether there are differences in the types of technologies pursued by established firms compared to startup firms. Using logistic regression analysis, Munteanu found that the odds ratio of invention licensing by startup firms relative to invention licensing by established firms was lower for later stage inventions and higher for earlier stage inventions. Invention licensing by established firms was positively correlated with later invention development stage. Munteanu’s study does not specifically answer the research question of the proposed study. Moreover, there are several issues with the approach Munteanu used that the proposed study addresses. I will explore these issues in detail in later sections of this paper.

Understanding the Potential Influence of Development Stage

The issue of development stage posed in the preliminary research question of the proposed study goes to the premise of current public policy related to university technology transfer. Federal policy in general seems to presume that development stage is not a factor in the successful transfer of technologies derived from federally-funded R&D to the private sector. It seems to presuppose that profit-driven and mission-driven organizations or aspiring entrepreneurs (i.e., individuals or small teams of a few people) will have access to the resources necessary to successfully employ the technologies for various applications that will benefit the public interest and the motivation to pursue such opportunities regardless of the development state of the technology. However, it appears that this assumption has never been tested or validated.

The results of the proposed research study will likely have significant implications for federal policy regarding university technology transfer. If development stage is not a factor in the successful university technology transfer, we can definitively remove it from the discussion and focus our resources on pursuing other candidates to explain why so few university-created technologies make their way to the private sector. Development stage will be removed as an excuse for why research institutions, particularly universities, do not transfer a higher percentage of the technologies they create with the support of federal funding to the private sector. However, if development stage is in fact explanatory, then it becomes necessary for the government to reconsider the extent of its participation in the research and development process as well as the structures and mechanisms it uses to fund those activities.

Development stage has not been extensively investigated as a determinant of technology transfer outcomes. There is popular belief among many technology transfer professionals that a technology must progress to a certain minimum state of development (i.e., development stage) before it can be successfully transitioned to the private sector. Discussions among industry professionals about the so called “Valley of Death” are founded upon this belief. The Valley of Death refers to the gap between funding provided by the federal government for basic research that produces scientific discoveries and funding provided by the private sector for research and development activity directed toward the exploitation of such discoveries in specific applications for which there is user demand (see, e.g., Ferguson, 2014; Gildbrandsen, 2009; Hudson & Khazragui, 2013). Many technology transfer professionals point to this gap as a primary impediment to successfully transferring technologies to the private sector.

The literature provides evidence to suggest that development stage plays an important role in successful university technology transfer. A key finding of Lee (1997) was that private sector firms are unlikely to invest in commercializing technologies generated from the research conducted at universities unless they are significantly de-risked. Even research that highly focused applied research in nature requires significant funding to de-risk the resulting technologies. Private sector firms seem unwilling to spend funds to de-risk such technologies. Wu, Welch, and Huang (2015) found a positive correlation between additional post-disclosure research conducted by faculty inventors and the execution of a license for the patents on inventions that resulted from the research.

Munteneau (2012) and Wang, Eltayyar, Wu, & Xiang (2016) are among the few examples where development stage has been explicitly considered in the study of technology transfer. There is literature that discuss the technology readiness level (TRL) scale as a measure of development stage (see, e.g., EARTO, 2014; Mankins, 1995; Mankins, 2009; Nolte & Kruse, 2011; Olechowski, Eppinger, & Joglekar, 2015), but most of these sources merely describe the scale or discuss applications of it. They provide very little insight into the potential role of development stage in university technology transfer.

The insights offered by Stokes (1997) have significant implications for examining the potential role of development stage in university technology transfer. Stokes examined the core paradigm that provides the framework for federally-funded research and development as well as the implications that framework has for public policy. Based on both experience and reasoned analysis, he argued that the static and dynamic variants of the predominant linear paradigm relating science and technology is fundamentally flawed. This paradigm posits that pure basic research is the fountain from which all technological progress springs forth. In the dynamic linear paradigm, basic research leads to applied research which gives way to development which subsequently results in production and operations technologies. Stokes demonstrated that this one-dimensional linear model is inadequate and inaccurate in describing reality.

Stokes (1997) noted several attempts by previous scholars to develop alterative models that more correctly described the interaction between understanding and use in scientific research and technological progress. Stokes offered a two-dimensional framework to comprehend the relationship between understanding and use in the pursuit of scientific knowledge. The vertical axis indicated the degree to which research strives for fundamental understanding of phenomenon and ranges from no concern for fundamental understanding to complete focus on developing fundamental understanding. The horizontal axis indicated the degree to which research is inspired by considerations of use and ranges from no consideration to completely use-driven. This framework produces a four-quadrant model of scientific research.

In the model Stokes (1997) put forward, pure applied research is positioned in the lower right quadrant. Pure basic research is in the upper left quadrant. The upper right quadrant exemplifies use-inspired basic research. One might conceive of the lower left quadrant as descriptive research. Stokes also noted the trajectory of technology is not just dictated by technical considerations. Market considerations also have a profound influence on the development, adoption, and continued use of technology.

The Role of Organizations in University Technology Transfer

Most university technology transfer activity occurs in an organizational context. In testimony to a hearing held by the U.S. House of Representatives, U.S. Department of Commerce Undersecretary for Technology Robert M. White pointed out that technology transfer is fundamentally a business decision on the demand side of the process (Barriers to Domestic Technology Transfer, 1992). The participants in university technology transfer are the universities that create the technologies and established business entities (whether for-profit or non-profit) or aspiring entrepreneurs (i.e., individuals or small teams of a few people) who generally act with the backing of stakeholder groups with the goal of creating organizations for realizing the application of technologies for various intended purposes.

It therefore seems reasonable to discuss university technology transfer at the organizational level. As Simon (1991) explains, “some phenomena are more conveniently described in terms of organizations and parts of organizations than in terms of the individual human beings who inhabit those parts” (p. 126). University technology transfer is one such phenomenon.

However, I employ a postmodern conceptualization of organizations for the purposes of the proposed study. In the postmodern approach, organizations are “sets of recursive practices sustained by resource appropriation and rules” (Miller & Fox, 2019, p. 90). An organization is nothing more than a human construct defined by the norms and expectations of its members who must continually negotiate and affirm those norms and expectations. It is simply a way that a group of people have settled on interacting to achieve agreed upon objectives. In this sense, the term *organization* connotes both a type of group and the malleable repeated patterns of social interactions employed by the members of a group. This is significantly different from the traditional conceptualizations of organizations as physical objects and life-like entities capable of acting on their own distinct motivations.

The postmodern conceptualization of organizations has long roots. Simon (1997) noted in its earliest editions as far back as the late 1940s that organizations can be conceptualized as patterns of group behavior in a very broad sense (p. 110). Simon argued that the term organization simply referred to the relations among a group of people (p. 19). Moreover, he maintained that decisions associated with carrying out the physical tasks of achieving the agreed upon objectives of an organization are not made by the organization *per se* but by people acting as members of the organization (p. 281). As such, a decision to acquire and use a technology is made by one or more members of an organization (e.g., a for-profit company) acting in accordance with the agreed upon guidelines that govern their behavior regarding such matters.

Organizations can obtain some technology (i.e., information) without much cost while they may need to expend significant resources to acquire other technology. When expending resources to acquire technology, there is the risk of a degradation in the organization’s circumstance because of uncertainty about whether the technology will enable the organization to achieve its objective. Organizations evaluate the attainment of the objectives in terms of desired outcomes (i.e., preferences). However, it is possible for one preference to conflict with another. As such, there is also the risk that making use of an acquired technology can positively impact one preference while negatively impacting another.

Organizations participating in the market for technology are faced with the task of making choices under uncertainty. Each available technology choice has an unknown and uncertain probability of helping the organization realize certain preferences and produce a net improvement in its circumstances. Under such circumstances, how do organizations make decisions regarding opportunities to acquire technology.

Decision Making in an Organizational Context

There are three general scenarios concerning the environment in which organizations must make technology acquisition decisions. There could be far more technology available than organizations can effectively use. Alternatively, organizations could have excess capacity and resources for acquiring and applying technology that are unused because of a dearth of technology that satisfies their preferences. Finally, it’s possible that both preceding scenarios co-exist. There could be more technology available than organizations can effectively use and at the same time organizations amenable to acquiring technology may elect not to pursue technology that is available because what is available simply does not meet their requirements. In an environment where organizations are faced with more opportunities to acquire technology than there are resources to make use of them, how and why does an organization choose to pursue one technology and not another? If organizations are amenable to acquiring and applying technology and have the capacity and resources to do so but have chosen not to, why do they choose not to pursue available technology that appears relevant to their missions and motives? The discourse on organizational theory and behavior as well as descriptive decision theory provides some insights.

A great deal of research on organizational decision-making is normative in nature and focuses on how individual decision makers within organizations should make decision (March 1997). However, “it is so far from how one lives to how one should live that he who lets go of what is done for what should be done learns his ruin rather than his preservation” (Machiavelli, 1532, p. 61). To effect successful desired change, policymakers must act in accordance with the world as it is, not as they believe it should be. Consequently, the foundation for the design of this study is descriptive organizational decision theory and how organizations actually make decisions rather than normative organizational decision theory and how they should make them.

Much, if not most, of current theory about organizational decision-making is based on psychological studies of individual decision-making (March, 1997). However, research has demonstrated that context can significantly affect the decision-making process and decisions of individuals (Kahneman & Tversky, 1980; Kahneman & Tversky, 2013; Tversky & Kahneman, 1992). Whether one is making a decision solely for one’s own benefit or within one’s role as a member of an organization seems to be an important contextual distinction. It seems reasonable to presume that decision-making in an organization is likely to be much more of a socially-driven phenomenon than decision-making that is purely personal. As such, it is sensible to conclude theories and frameworks from studies of individual decision making in the psychological literature may not translate directly to organizational decision-making without significant modification. It is important to understand how organizational decision-making may differ from individual decision-making which will likely provide insight into the role of development stage in organizations’ decisions about the acquisition of technology.

Organizations seeking to engage in technology transfer are bounded not just by the constraints of the cognitive capacities of their people, finite time frames, and limited data (March, 1997) but also resource limitations that constrain their capacities for seeking, acquiring, and using new technology.

It’s reasonable to assume that organizations faced with uncertain choices regarding technology that they can possibly acquire to help achieve their purposes will seek additional data and information try to reduce the uncertainty surrounding the likelihood of being able to successfully use the technology. This additional data and information includes meta-information about the technology itself (i.e., information about information).

One can presume that there is little need for organizations to expend significant resources actively seeking opportunities or conducting exhaustive rational evaluations of each opportunity before making a choice. According to bounded rationality, organizations in such situations should and will use heuristics to make their decisions (March, 1997).

Development Stage and Technology Transfer Outcomes

Based on my professional experience and review of the literature, I hypothesize that development stage helps explain why private sector companies do not to pursue the acquisition and use of university-created technologies that seem to align with their missions and profit motives even when they seem to have the resources to do so.

While the literature that explicitly examines the role of development stage in university technology transfer is sparse, various scholars have explored the relevant issues under various monikers and in different ways. In my review of the literature, I found only one study that specifically examined the association between development stage and technology transfer. Munteanu (2012) provides useful insight into the topic. However, there are substantial opportunities to improve upon both the approach and the results of Munteanu. Moreover, there are important differences between the research design used by Munteanu and this study. These differences have implications for the generalizability of the results and their usefulness in formulating public policy.

Munteanu (2012) used an approach to study the role of development stage in technology transfer that is the typical of studies about technology transfer in general. Munteanu applied economics-based rational choice theory. The study also incorporated comparative advantage theory to understand differences between startup firms and established firms, although it didn’t explicitly define either category. As such, it is not clear what criteria Munteanu used as the basis for classifying each case in the analysis.

Munteanu (2012) was a quantitative empirical design that used correlational regression analyses, which again is typical of studies about the topic. The study operationalized the concept of technology as disclosures of patentable subject matter. It operationalized technology transfer as executed licenses for patented inventions assigned to universities and income generated from those licenses. This is typical of technology transfer studies but is perhaps overly narrow as I will further discuss a bit later. Development stage was the primary explanatory variable. Munteanu used an ordinal level of measure for development stage and a scale conceived by the researcher. However, there is no evidence that any type of validity analysis was performed for this scale. The scale itself is somewhat arbitrary and subjective. The analysis included several control variables related to the characteristics of the inventor and the type of invention. Munteanu used a nominal level of measure for invention type that employed categories conceived by the researcher. Like many other technology transfer studies, the categories for type of invention used by Munteanu were somewhat arbitrary and subjective. Again, there is no evidence that any type of validity analysis was conducted for the nominal categories. The data used in Munteanu was a census of 700 inventions disclosed to the University of California – San Diego between January 1, 1986 and December 31, 2003. However, it is not clear if the analysis included all disclosures during this period or only disclosures that resulted in an allowed patent.

The research question examined by Munteanu (2012) was whether there are differences in the types of technologies pursued by established firms compared to startup firms. However, the criteria for what constitutes an established firm versus a startup firm was not specified. Munteanu theorized that under the theory of comparative advantage, established firms and startup firms would seek to acquire technologies of different development stages. Munteanu tested two primary hypotheses. The first hypothesis was that established firms are more likely to license inventions in the “ready” stage of development than inventions in earlier stages of development. The second hypothesis was that start-up firms are more likely to license inventions in the “conceptual” stage of development than inventions in later stages of development.

The study tested these hypotheses based on four key assumptions. First, economies of scale and informational asymmetries are important criteria in licensing decisions of firms. Second, established firms have a comparative advantage to startup firms in commercializing inventions that are ready for manufacturing. Third, startup firms have a comparative advantage to established firms in commercializing inventions at the conceptual stage. Fourth, the past licensing experience of inventors increases inventor propensity to pursue commercialization of inventions. Munteanu applied these assumptions without providing any evidence of their reasonableness.

Munteanu (2012) found sufficient evidence to reject the null hypotheses in favor of the alternative hypotheses. The odds ratio of invention licensing by startup firms relative to invention licensing by established firms was lower for later stage inventions and higher for earlier stage inventions. Invention licensing by established firms was positively correlated with later invention development stage.

While insightful, Munteanu (2012) does not specifically answer the research question put forward for the proposed study. The nature of the sample used by Munteanu significantly limits the generalizability of the study’s results. Moreover, the study by Munteanu only establishes correlation, not causation. Although the results obtained by Munteanu can be taken as *prima facie* evidence that comparative advantage may lead certain types of private sector firms to prefer earlier or later stage technologies, they do not rule out other causes or potential dynamics. For example, startup companies may actually prefer later stage technologies but may not have the resources to competitively bid for such technologies. As such, startup companies may simply settle for earlier stage technologies because they are forced to do so, not because they have a comparative advantage in commercializing earlier stage technologies. Also, given the uncertainty surrounding how Munteneau categorized technologies by development stage, it’s quite possible that any correlation observed was a product of the method used to categorize technologies by development stage and not anything fundamental to the nature of university technology transfer or the way that private sector firms operate.

Baek, Hwang, and Park (2018) included development stage (i.e., degree of technology maturity) as a factor in their analysis of technology transfer. They used regression analysis to examine the correlations between various independent variables and successful technology transfer which they operationalized as the execution of a contact to use a technology. They operationalized development stage as the TRL level before research and development and TRL level after research and development. Baek, Hwang, and Park did find a statistically significant correlation between TRL level after research and development and successful technology transfer. However, this study has limited generalizability to university technology transfer in the United States. It focused only on railroad projects in South Korea, which has a significantly different economic system than the United States. It also did not address causality in the relationship between development stage and technology transfer success.

Song, Park, & Park (2017) examined factors that could potentially influence business decisions about commercializing technology transferred from government research institutes (GRIs) to small and medium-sized enterprises (SMEs). They included technology maturity as a potential explanatory factor. They operationalized successful technology transfer as a dichotomous variable indicating the licensee’s intention to conduct additional research and development on the technology. The authors did not find a statistically significant association between technology maturity and technology transfer success as defined in the study. However, this study also has limited generalizability to university technology transfer in the United States. Song, Park, and Park used a five-point Likert scale to measure technology maturity. There is no indication that they validated the scale prior to using it. The way the authors operationalized successful technology transfer also may have been problematic. Moreover, the authors conducted the study in South Korea in the context of an economic system that is significantly different than that for the United States.

While there appears to be few studies that have explicitly examined the role of development stage in university technology transfer, there is ample evidence in the literature that allude to it. A statement from the Michigan Biotechnology Institute (MBI) submitted for the record of a hearing in the U.S. House of Representatives discussed MBI’s efforts to advance technology from the pre-competitive stage to a stage that is useful to industry (Barriers to Domestic Technology Transfer, 1992). Fraser (2010) also pointed out the increasing use of gap funding among universities to help make the transition from research and development to the market – the so called “valley of death.” Chu (2013) discussed a program the Los Angeles campus of the University of California implemented to close the gap between the state of a technology where federal funding ends and the point where the private sector is willing to partner to make use of the technology. Likewise, Spearing (2013) emphasized the importance of mechanisms to move university-created technology to the point where it is useful and can be transitioned to the private sector. Such observations suggest a relationship between development stage and successful technology transfer.

The Valley of Death in University Technology Transfer

There have been numerous studies (see, e.g., Markham, 2002; Markham, Ward, Aiman-Smith, & Kingon, 2010; Tirpak, 2017; Wessner, 2005) on the so called “valley of death” – a reference to the gap between basic research and applied research in which promising technologies are often abandoned because of an inability to attract sufficient funding to support the R&D activities necessary to further their development. Many of these studies seem to allude to an association between development stage and successful technology transfer. They generally employ a three-stage framework that describes the progress of technology from laboratory to market.

Wessner (2005) observed that many private venture capital markets are unwilling to fund promising but risky concepts for commercializing technologies that have not been validated. He highlighted the advanced technology program (ATP) has as an example of the success that can be achieved when funding is provided to advance the development stage of technologies to a point of commercial viability that is more suitable for private sector involvement. According to Wessner, this approach has led to the successful transfer of fuel cell, proteomics, medical diagnostic, and lithography technologies. Moreover, Wessner argues there is clear evidence that ATP helped attract the private investment necessary to successfully transfer technologies to offerings in the private sector that benefited the public interest.

Murphy and Edwards (2003) examined the difficulties of transitioning publicly-funded, early-stage ventures attempting to apply new energy technologies to create commercial offerings across the so-called “valley of death.” They argued that such ventures fail to obtain private sector funding because here are “significant gaps between what the ventures are offering to investors and what the potential investors are seeking” (p. 4). Murphy and Edwards observed that the need to justify budgets and demonstrate public benefits in an unrealistically short time frame pressures federal agencies to accelerate handing-off technologies to the private sector in a way that is often abrupt and ineffective. The private sector typically focuses on investment opportunities that are at a later stage of development than what is normally the case with opportunities related to research and development projects at the point when public sector funding is ending (Murphy & Edwards). Moran (2007) noted a similar phenomenon in drug discovery characterized by a widening in the gap between the end-point of traditional funding support for academic research and development and the development stage of projects that the private sector is interested in supporting or acquiring. According to Murphy and Edwards, private sector investors view technologies derived from federally-funded research and development as much less advanced than do the public-sector sponsors of that research and development. Moreover, the private sector is interested in businesses, while the output of research and development is technology. The two are not synonymous.

The existence of the “valley of death” phenomenon strongly supports the theory that development stage is a significant factor in technology transfer outcomes. However, it is not definitive proof. There may be other scenarios that could produce the phenomenon. For example, it could simply be a matter of supply of labor. Some scholars have posited that product champions, driven by some motivation, shepherd projects across the “valley of death” (Markham 2002; Markham, Ward, Aiman-Smith, & Kingon, 2010). Development stage may not be a significant factor for these champions. The phenomenon we call the “valley of death” could be nothing more than an imbalance between supply of champions and demand for champions much like shortages seen in other professions and industries, such as the dearth of engineers or programmers. Another scenario is that some factor other than development stage, such as technology category, is the primary determinant between those technologies that successfully cross the “valley of death” and those that don’t.

Development Stage in Federal Technology Transfer Policy

Federal technology transfer policy does not explicitly and directly address development stage but there are aspects that one can use to draw some conclusions about the role of development stage in relevant federal public policy regarding technology transfer. Murphy and Edwards (2003) argued that the federal government considers the commercialization of technologies created from federally-funded research and development as the responsibility of the private sector. For example, the Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) expect private sector firms to develop offerings based on its technologies and introduced them to the marketplace. There are two primary principles that significantly influence federal public policy regarding technology transfer. The first principle is that the federal government should not pick winners and losers in the private sector. The second is that the federal government should not encourage a dependence on federally provided financial support (i.e., “corporate welfare”) among the private sector (Murphy and Edwards).

The Small Business Innovation Research (SBIR) program created by the Small Business Innovation Development Act of 1982 (Pub.L. 97-219) considers development stage in a broad sense. The program is structured into three phases – feasibility (Phase I), development (Phase II), and commercialization (Phase III). However, the federal government only provides funding for the first two phases. Projects generally are focused on addressing identified needs within federal agencies. The NSF is the only agency that has broadened its SBIR program to consider projects more generally aligned with the overall mission of the agency that seek to serve private sector markets. However, only small businesses as defined by the government are eligible to participate in the program. Moreover, it accounts for less than three percent (3%) of the extramural research and development budgets of federal agencies. Even more, projects aren’t necessarily connected with technologies derived from previous federally-funded research and development programs (U.S. Small Business Administration, n.d.).

Studies of federal technology transfer policy typically have not focused on development stage. One of the most glaring issues about studies of federal policy regarding technology transfer in general is the narrow focus on either the Bayh-Dole Act of 1980 (Dai, Pop & Bretschneider, 2005) or the Small Business Innovation Research (SBIR) program that was created by Pub.L. 97-219 The Small Business Innovation Development Act of 1982 (see, e.g., Andersen, Bray & Link, 2017; Joshi, Inouye & Robinson, n.d.; Link & Scott, 2010). Other research has ventured into the broader innovation policy of the United States (see, e.g., Hemel, Ouellett & Larrimore, 2019). My review of the literature revealed no current studies that specifically investigated the issue of development stage in federal technology transfer policy. Many of the studies I unearthed that provided policy options regarding federal technology transfer policy were generally formative evaluation studies for specific programs, particularly the SBIR program.

Kochenkova, Grimaldi, and Munari (2016) examined 46 studies that either explicitly referenced public support mechanisms to facilitate university technology transfer activities or conducted investigations of single policy measures or sets of measures aimed at technology transfer. They found that the primary public policy measures studied in the literature included legislative and institutional measures, direct financial measures, and competence-building measures. In general, all the studies were focused on either policy design or impact assessment. A significant number of the studies focused on the design of intellectual property rights. Relatively fewer studies detailed the impact public policy measures had on actual university technology transfer rates and outcomes. None of the studies appeared to address the issue of development stage.

Conclusion

This literature review sought to identify the relevant conceptual and theoretical frameworks for a proposed study of the role of development stage in university technology transfer. In broad terms, the proposed study aims to provide insight into why private sector organizations choose not to pursue the acquisition and use of university-created technologies that seem to align the with their mission and profit motives even when the organizations appear to have the resources to do so. More specifically, the proposed study seeks to examine the notion commonly held among technology transfer professionals that the development stage of a technology greatly influences the likelihood that the technology will be transferred to the private sector for use that benefits the public interest. If an effect is found, this proposed study also seeks to determine the causal mechanism for it.

The literature review focused on two primary lenses through which I propose to examine the study the topic. The public-sector economics perspective helps to understand the implications of conceiving technology and technology transfer as impure public goods and merit goods. The perspective of organizational theory and behavior and decision theory provides theories and frameworks for understanding organizational decision making. The literature review also identified additional theoretical and conceptual frameworks and provided insights applicable for the proposed study. This included conceptualizations and operationalizations of development stage, evidence suggesting the potential influence of development stage on the university technology transfer process, and whether and how development stage is addressed in federal public policy regarding university technology transfer.

The literature provides support for the proposed conceptualization of technology and university technology transfer. It also demonstrates the impure public good nature of both technology and university technology transfer as well as the merit good nature of university technology transfer. These aspects of technology and university technology transfer are the source of various types of market failure that provide the core rationale for government intervention in university technology transfer.

The review also highlighted the challenges and gaps found in the literature regarding university technology transfer. The definition of technology as it relates to public policy has become overly narrow. Currently used metrics do not capture and measure all types of university technology transfer. Studies of university technology transfer have typically examined the topic from the supply side and have relied on regression analysis using data obtained from AUTM. Consequently, the determinants of success found in the literature tend to emphasize factors exogenous to the technology transfer process itself such as institutional features and researcher characteristics. I only found one study that explicitly focused on the relationship between development stage and success in university technology transfer. However, because of the structure of this investigation it did not answer the research question of the proposed study.

Based on my review of the literature, I have formulated a hypothesis regarding the influence of development stage in university technology transfer outcomes.

References

Amador, X. (2012). *I’m not sick, I don’t need help!: How to help someone with mental illness accept treatment*. Peconic, NY: Vivida Press.

American Association for the Advancement of Science [AAAS]. (2018a). Defense, Nondefense, and Total R&D, 1976-2018 [Data file]. Retrieved from https://www.aaas.org/page/historical-trends-federal-rd

American Association for the Advancement of Science [AAAS]. (2018b). University Science & Engineering R&D Funding by Source, 1990-2017 [Data file]. Retrieved from https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd

Anatan, L. (2015). Conceptual issues in university to industry knowledge transfer studies: A literature review. *Procedia - Social and Behavioral Sciences, 211*, 711-717. doi:10.1016/j.sbspro.2015.11.090

Anderson, T. R., Daim, T. U. & Lavoie, F. F. (2007). Measuring the efficiency of university technology transfer. *Technovation, 27*(5), 306-318. doi:10.1016/j.technovation.2006.10.003

Arshadi, N., & George, T. F. (2008). The Economics of University Research and Technology Transfer. *Research Management Review, 16*(1), 1-19. Retrieved from http://lib.slu.edu

Baek, S., Hwang, S., & Park, Y. I. (2018). Determinants of Technology Transfer and Commercialization in National Research and Development: Focusing on Korea Railroad Research Projects. *Asian Journal of Innovation & Policy, 7*(3), 438-456. doi:10.7545/ajip.2018.7.3.438

Banke, J. (2010). Technology readiness levels demystified. *Aeronautics.* Retrieved August 24, 2018 from https://www.nasa.gov/topics/aeronautics/features/trl\_demystified.html

*Barriers to domestic technology transfer: Hearing before the Subcommittee on Oversight and Investigations of the Committee on Energy and Commerce, House of Representatives*, 102nd Congress, First Session (1992).

*Barriers to domestic technology transfer: Hearing before the Subcommittee on Oversight and Investigations of the Committee on Energy and Commerce, House of Representatives*, 102nd Congress, First Session (1992) 145 (testimony of Robert M. White).

Blank, S., & Dorf, B. (2012). The startup owner’s manual: The step-by-step guide for building a great company. Pescadero, CA: K&S Ranch, Inc.

Bohn, R. E. (1994). Measuring and managing technological knowledge. *Sloan Management Review, 36*(1), 61-73. Retrieved from https://www.researchgate.net/profile/Roger\_Bohn/publication/237010832\_Measuring\_and\_Managing\_Technological\_Knowledge/links/5b40271d458515f71cad127f/Measuring-and-Managing-Technological-Knowledge.pdf

Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy, 29*(4,5), 627-655. Retrieved from http://lib.slu.edu

Bush, G. H. W. (1992). Remarks at the National Technology Initiative Conference in Chicago, Illinois. *Public Papers of the Presidents of the United States: George H. W. Bush (1992-1993, Book II)*, 1641-1646. Retrieved from https://www.govinfo.gov/app/details/PPP-1992-book2/PPP-1992-book2-doc-pg1641

Bush, V. (1945). *Science, the endless frontier. A report to the President*. Washington, D.C.: Government printing office.

Cairney, P. (2016). *What is Policy?* Retrieved April 11, 2019, from https://paulcairney.wordpress.com/2016/03/04/what-is-policy-3/

Carlsson, B., & Fridh, A.-C. (2002). Technology transfer in United States universities: A survey and statistical analysis. *Journal of Evolutionary Economics, 12*(1/2), 199. doi:10.1007/s00191-002-0105-0

Chu, B. (2013). Fostering technology transfer, innovation, and entrepreneurship from the perspective of a public university. In K. Hishida (ed.), *Fulfilling the promise of technology transfer: Fostering innovation for the benefit of society* (pp. 59-70). Springer.

Clinton, W. J. (2000). Statement on Signing the Technology Transfer Commercialization Act of 2000. *Weekly Compilation of Presidential Documents*, 36(44), 2718-2719. Retrieved from https://www.govinfo.gov/content/pkg/WCPD-2000-11-06/pdf/WCPD-2000-11-06-Pg2718-3.pdf

Congressional Budget Office [CBO]. (2018). Historical Budget Data [Data file]. *The Budget and Economic Outlook: 2018 to 2028*. Retrieved from https://www.cbo.gov/about/products/budget-economic-data#2

*Daily Compilation of Presidential Documents*. (2011, October 28). Retrieved from https://www.govinfo.gov/app/collection/CPD/

Desmarais-Tremblay, M. (2017). A genealogy of the concept of merit wants. *European Journal of the History of Economic Thought, 24*(3), 409-440. doi:10.1080/09672567.2016.1186202

Develop. (n.d.). *Merriam-Webster.com dictionary* [Website]. Retrieved May 13, 2020, from https://www.merriam-webster.com/dictionary/develop

Develop. (2020). *Cambridge dictionary* [Website]. Cambridge University Press. Retrieved May 13, 2020 from https://dictionary.cambridge.org/us/dictionary/english/develop

Development. (2020). *Cambridge dictionary* [Website]. Cambridge University Press. Retrieved May 13, 2020 from https://dictionary.cambridge.org/us/dictionary/english/development

Dolmans, S. A. M., Shane, S., Jankowski, J., Reymen, I. M. M. J., & Romme, A. G. L. (2016). The evaluation of university inventions: Judging a book by its cover? *Journal of Business Research, 69*(11), 4998-5001. doi:10.1016/j.jbusres.2016.04.070

Dye, T. R. (1976). *Understanding public policy.* Upper Saddle River, NJ: Prentice-Hall.

European Association of Research and Technology Organisations [EARTO]. (2014). *The TRL Scale as a Research and Innovation Policy Tool*. Retrieved from http://www.earto.eu/fileadmin/content/03\_Publications/The\_TRL\_Scale\_as\_a\_R\_I\_Policy\_Tool\_-\_EARTO\_Recommendations\_-\_Final.pdf

Feibleman, J. K. (1961). Pure science, applied science, technology, engineering: An attempt at definitions. *Technology and Culture, 2*(4), 305. Retrieved from https://www.jstor.org/stable/pdf/3100886.pdf

Fellnhofer, K. (2015). Literature review: investment readiness level of small and medium sized companies. *International Journal of Managerial and Financial Accounting*, 7(3/4), 268-284. Retrieved from https://www.researchgate.net/profile/Katharina\_Fellnhofer/publication/291670426\_Literature\_Review\_Investment\_Readiness\_Level\_of\_Small\_and\_Medium\_Sized\_Companies/links/57e80d2908ae9e5e4558c179/Literature-Review-Investment-Readiness-Level-of-Small-and-Medium-Sized-Companies.pdf

Ferguson, W. K. (2014). *A Policy Framed Analysis of the Valley of Death in U.S. University Technology Transfer.* University of Southern Mississippi. Available from http://www.proquest.com/en-US/products/dissertations/individuals.shtml

Fraser, J. (2010). Academic technology transfer: Tracking, measuring and enhancing its impact. *Industry and Higher Education, 24*(5), 311-317. Retrieved from http://lib.slu.edu

Frické, M. (2019). The Knowledge Pyramid: the DIKW Hierarchy. *Knowledge Organization*, 46(1), 33-46. doi:10.5771/0943-7444-2019-1-33

González-Pernía, J. L., Kuechle, G., & Peña-Legazkue, I. (2013). An assessment of the determinants of university technology transfer. *Economic Development Quarterly, 27*(1), 6. Retrieved from http://lib.slu.edu

Gulbrandsen, K. E. (2009). *Bridging the valley of death: The rhetoric of technology transfer.* Iowa State University, Ann Arbor. Available from http://www.proquest.com/en-US/products/dissertations/individuals.shtml

Gulbrandsen, M., & Rasmussen, E. (2012). The use and development of indicators for the commercialisation of university research in a national support programme. *Technology Analysis and Strategic Management, 24*(5), 481-495. doi:10.1080/09537325.2012.674670

Hallam, C. R. A., Wurth, B., & Mancha, R. (2014). University-industry technology transfer: a systems approach with policy implications. *International Journal of Technology Transfer & Commercialisation, 13*(1-2), 57.

Heisey, P. W., & Adelman, S. W. (2011). Research expenditures, technology transfer activity, and university licensing revenue. *Journal of Technology Transfer, 36*(1), 38-60. doi:10.1007/s10961-009-9129-z

Herschbach, D. R. (1995). Technology as knowledge: Implications for instruction. *Volume 7 Issue 1 (fall 1995)*. Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/8589/herschbach.pdf?sequence=1

Herzberg, F., Mausner, B., & Snyderman, B. (1959). *The Motivation to Work (2nd ed.).* New York: John Wiley.

Herzog, R. M., & Wasden, C. (2013). Managing life science innovations in public research through holistic performance measures. In K. Hishida (ed.), *Fulfilling the promise of technology transfer: Fostering innovation for the benefit of society* (pp. 83-94). Springer.

Hishida, K. (Ed.) (2013). *Fulfilling the promise of technology transfer: Fostering innovation for the benefit of society*. Tokyo: Springer.

Hudson, J., & Khazragui, H. F. (2013). Into the valley of death: research to innovation. *Drug Discovery Today, 18*(13-14), 610-613. Retrieved from https://purehost.bath.ac.uk/ws/files/9594981/Hudson\_Drug\_Discovery\_Today\_2013.pdf

Ismail, M., Hamzah, S. R. a., & Bebenroth, R. (2018). Differentiating knowledge transfer and technology transfer: What should an organizational manager need to know? *European Journal of Training & Development, 42*(9), 611-628. doi:10.1108/EJTD-04-2018-0042

Kahneman, D., & Tversky, A. (1980). Prospect theory. *Econometrica*, *12*.

Kahneman, D., & Tversky, A. (2013). Prospect theory: An analysis of decision under risk. In *Handbook of the fundamentals of financial decision making: Part I* (pp. 99-127).

Kim, J., Diam, T. U., & Anderson, T. R. (2009). *University technology transfer: A conceptual model of impacting factors and phased process*. Paper presented at the 2009 Portland International Conference on Management of Engineering and Technology, Portland, OR. doi: 10.1109/PICMET.2009.5261803

Kochenkova, A., Grimaldi, R., & Munari, F. (2016). Public policy measures in support of knowledge transfer activities: A review of academic literature. *The Journal of Technology Transfer* (3), 407. doi:10.1007/s10961-015-9416-9

Kohler, H. (1992). *Microeconomics*. Lexington, MA: D. C. Heath and Company.

Kundu, N., Bhar, C., & Pandurangan, V. (2015). Managing Technology Transfer: An Analysis of Intrinsic Factors. *South Asian Journal of Management, 22*(3), 69-95. doi:Retrieved from http://lib.slu.edu

Kuo, P. S., Lin, Y. S., & Peng, C. H. (2016). International Technology Transfer and Welfare. *Review of Development Economics, 20*(1), 214-227. doi:10.1111/rode.12212

Lall, S. (Ed.) (2001). *The economics of technology transfer*. Northampton, MA: Edward Elgar Publishing, Inc.

Lee, Y. S. (Ed.) (1997). *Technology transfer and public policy*. Westport, CT: Quorum Books.

Leonard-Barton, D. (1990). The intraorganizational environment: Point-to-point versus diffusion. In F. Williams & D. V. Gibson (Eds.), *Technology transfer: A communication perspective* (pp. 43-62). Sage Publications.

Libecap, G. D. (Ed.) (2009). *Measuring the social value of innovation: A link in the university technology transfer and entrepreneurship equation* (Vol. 19). Bingly, United Kingdom: Jai Press.

Link, A. N., & Scott, J. T. (2019). The economic benefits of technology transfer from U.S. federal laboratories. *The Journal of Technology Transfer* (5), 1416. doi:10.1007/s10961-019-09734-z

Link, A. N., Siegel, D. S., & Wright, M. (Eds.). (2015). *The Chicago handbook of university technology transfer and academic entrepreneurship*. Chicago, IL: The University of Chicago Press.

Machiavelli, N. (1532). *The prince* (H. C. Mansfield, Jr., Trans. 1985). Chicago, IL: The University of Chicago Press.

Mankins, J. C. (1998). Research and development degree of difficulty: A white paper. Washington, DC: Advanced Projects Office, Office of Space Flight, National Aeronautics and Space Administration (NASA). Retrieved from http://www.economicswebinstitute.org/essays/nasadiff.pdf

Mankins, J. C. (2009). Technology readiness assessments: A retrospective. *Acta Astronautica, 65*(9-10), 1216-1223. Retrieved from http://www.onethesis.com/wp-content/uploads/2016/11/1-s2.0-S0094576509002008-main.pdf

Mankins, J. C. (1995). Technology readiness levels: A white paper (edited December 22, 2004). Washington, DC: Advanced Concepts Office, Office of Space Access and Technology, National Aeronautics and Space Administration (NASA). Retrieved from http://www.artemisinnovation.com/images/TRL\_White\_Paper\_2004-Edited.pdf

March, J. G. (1997). Understanding how decisions happen in organizations. In Zur Shapria (Ed.), *Organizational decision making* (pp. 9-32). New York, NY: Cambridge University Press.

Marion, T. J., Dunlap, D., & Friar, J. H. (2015). Northwestern University: A study of technology transfer and the academic entrepreneur. In A. N. Link, D. S. Siegel, & M. Wright (Eds.)., *The Chicago handbook of university technology transfer and academic Entrepreneurship* (pp. 245-283). The University of Chicago Press.

Markman, G. D., Gianiodis, P. T., & Phan, P. H. (2009). Supply-Side Innovation and Technology Commercialization. *Journal of Management Studies, 46*(4), 625-649. doi:10.1111/j.1467-6486.2009.00835.x

Markham, S. K. (2002). Moving technologies from lab to market. *Research-Technology Management, 45*(6), 31-42. Retrieved from https://www.researchgate.net/profile/Stephen\_Markham/publication/228686775\_Moving\_Technology\_from\_Lab\_to\_Market/links/5405e1c60cf2bba34c1dd7cd/Moving-Technology-from-Lab-to-Market.pdf

Markham, S. K., Ward, S. J., Aiman‐Smith, L., & Kingon, A. I. (2010). The valley of death as context for role theory in product innovation. *Journal of Product Innovation Management, 27*(3), 402-417. Retrieved from http://lib.slu.edu

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review, 50(4)*, 370–96. doi:10.1037/h0054346

Mercelis, J., Galvez-Behar, G., & Guagnini, A. (2017). Commercializing science: nineteenth- and twentieth-century academic scientists as consultants, patentees, and entrepreneurs. *History & Technology, 33*(1), 4-22. doi:10.1080/07341512.2017.1342308

Miller, H. T., & Fox, C. J. (2019). *Postmodern Public Administration* (Revised edition). New York, NY: Routledge.

Mitcham, C., & Schatzberg, E. (2009). Defining technology and the engineering sciences. In A. W. Meijers (Ed.), *Philosophy of technology and engineering sciences* (Vol. 9, pp. 27-63). Burlington, MA: Elsevier.

Moran, N. (2007). Public sector seeks to bridge 'valley of death'. *Nature Biotechnology, 25*(3), 266-266. doi:10.1038/nbt0307-266

Müller, Hans & Maasdorp Christiaan. 2011. “The Data, Information, and Knowledge Hierarchy and its Ability to Convince.” In *2011 Fifth International Conference on Research Challenges in Information Science Proceedings*. Colette Rolland and Martine Collard (eds). Piscataway, NJ: Institute of Electrical and Electronics Engineers. doi:10. 1109/RCIS.2011.6006851

Munteanu, R. (2012). Stage of development and licensing university inventions. *International Journal of Management and Enterprise Development* (1). doi:10.1504/IJMED.2012.046796

Murphy, L. M., & Edwards, P. L. (2003). *Bridging the valley of death: Transitioning from public to private sector financing*: National Renewable Energy Laboratory Golden, CO.

Musgrave, R. A. (1959). *The theory of public finance: A study in public economy*. New York, NY: McGraw-Hill.

National Science Foundation, National Center for Science and Engineering Statistics [NCSES]. (2020). Survey of Federal Funds for Research and Development, Fiscal Years 2018-19. Retrieved May 7, 2020 from http://www.nsf.gov/statistics/fedfunds/

Nolte, W., & Kruse, R. (2011). Readiness level proliferation. *Air Force Research Laboratory, Tech. Rep. 88ABW-2011-5501*. Retrieved from https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2011/system/13132\_NolteWednesday.pdf

Office of Management and Budget [OMB]. (2002). *The President's Management Agenda*. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a394421.pdf

Office of Management and Budget [OMB]. (2018). *The President's Management Agenda*. Retrieved from https://www.whitehouse.gov/wp-content/uploads/2018/03/Presidents-Management-Agenda.pdf

Olechowski, A., Eppinger, S. D., & Joglekar, N. (2015). *Technology readiness levels at 40: A study of state-of-the-art use, challenges, and opportunities*. Paper presented at the 2015 Portland International Conference on Management of Engineering and Technology (PICMET), Portland, OR. Retrieved from http://web.mit.edu/eppinger/www/pdf/Eppinger\_PICMET2015.pdf

Olechowski, A. L., Eppinger, S. D., Tomaschek, K., & Joglekar, N. (2020). Technology readiness levels: Shortcomings and improvement opportunities. *Systems Engineering*, 23(2). doi:10.1002/sys.21533

Pfeffer, J. (1997). *New directions for organization theory: Problems and perspectives*.   
New York, NY: Oxford University Press.

Reagan, R. W. (1983). Memorandum on Government Patent Policy. *Public Papers of the Presidents of the United States: Ronald W. Reagan (1983, Book I)*. Retrieved from https://www.govinfo.gov/app/details/PPP-1983-book1

Rowley, J. (2007). The wisdom hierarchy: representations of the DIKW hierarchy. *Journal of information science, 33*(2), 163-180. doi:https://doi.org/10.1177%2F0165551506070706

Schatzberg, E. (2018). *Technology: critical history of a concept*. Chicago, IL: University of Chicago Press.

Schrier, E. (1964). Toward Technology Transfer: The Engineering Foundation Research Conference on “Technology and the Civilian Economy.” *Technology and Culture, 5(3)*, 344. https://doi-org.ezp.slu.edu/10.2307/3101252

Simon, H. A. (1991). Bounded rationality and organizational learning. *Organization Science, 2(1)*, 125-134. Retrieved from https://www.jstor.org/stable/2634943

Solow, R. (1957). Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics*, 39(3), 312-320. doi:10.2307/1926047

Song, M., Park, J. O., & Park, B. S. (2017). Determinants of R&D Commercialization by SMEs after Technology Transfer. *Asian Journal of Innovation & Policy, 6*(1), 45-57. doi:10.7545/ajip.2017.6.1.045

Spearing, M. (2013). University intellectual property exploitation: Personal perspectives from the UK and USA. In K. Hishida (ed.), *Fulfilling the promise of technology transfer: Fostering innovation for the benefit of society* (pp. 101-120). Springer.

Speser, P. L. (2012). *The art and science of technology transfer*. Hoboken, NJ: John Wiley & Sons.

Stage. (2020). Cambridge Dictionary [Website]. Cambridge University Press. Retrieved May 13, 2020 from https://dictionary.cambridge.org/us/dictionary/english/stage

Stevens, A. J. (2004). The enactment of Bayh-Dole. *Journal of Technology Transfer, 29*(1), 93-99. Retrieved from https://link-springer-com.ezp.slu.edu/content/pdf/10.1023%2FB%3AJOTT.0000011183.40867.52.pdf

Stiglitz, J., & Rosendard, J. (2015). *Economics of the public sector* (4th ed.). New York, NY:   
W. W. Norton & Company.

Stokes, D. E. (1997). *Pasteur's quadrant: Basic science and technological innovation*. Washington, D.C.: Brookings Institution Press.

Stoneman, P. (2002). *The economics of technological diffusion*. Malden, MA: Blackwell Publishers.

Tseng, A., & Raudensky, M. (2014). Assessments of technology transfer activities of US universities and associated impact of Bayh-Dole Act. *Scientometrics, 101*(3), 1851-1869. doi:10.1007/s11192-014-1404-6

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and uncertainty*, *5*(4), 297-323.

United Nations. (2017). *GDP and its breakdown at current prices in U.S. dollars* [Data file]. Retrieved from https://unstats.un.org/unsd/snaama/dnllist.asp

U.S. Department of the Treasury. (2018a). *Monthly Statement of the Public Debt of the United States, October 31, 2018*. Retrieved from https://www.treasurydirect.gov/govt/reports/pd/mspd/2018/2018\_oct.htm

U.S. Department of the Treasury. (2018b). *Monthly Treasury Statement: Receipts and Outlays of the United States Government, For Fiscal Year 2019 Through October 31, 2018, and Other Periods*. Retrieved from https://www.fiscal.treasury.gov/reports-statements/mts/previous.html

U.S. Small Business Administration. (n.d.). *About SBIR*. SBIR.gov [Website]. Retrieved May 21, 2020 from https://www.sbir.gov/about/about-sbir

U.S. Spending. (n.d.) *U.S. Government Spending*. Retrieved from https://www.usgovernmentspending.com/year\_spending\_2018USbn\_20bs2n\_4041\_605#usgs302

Wang, J., Eltayyar, M. E. S. S., Wu, J., & Xiang, L. (2016). The Grey Correlation Analysis between Technology Readiness Level and Performance in Civil Aircraft. *Journal of Grey System*, *28*(1), 109–117. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=112989107&site=eds-live

Wessner, C. W. (2005). Driving innovations across the valley of death. *Research Technology Management, 48*(1), 9-12. doi:10.1080/08956308.2005.11657289

Westerik, F. H. (2014). *Investor readiness: Increasing the measurability of investor readiness* (Master's thesis, University of Twente). Retrieved from https://essay.utwente.nl/64605/1/Westerik\_MA\_MB.pdf

Williams, F., & Gibson, D. V. (Eds.). (1990). *Technology transfer: A communication perspective*. Newbury Park, CA: Sage Publications.

Wilson, J. Q. (2006). Policy Analysis as Policy Advice. In M. Moran, M. Rein, & R. E. Goodin (Eds.), *The Oxford Handbook of Public Policy*, 152-168. New York: Oxford University Press.

Wilson, J. Q. (2006). Policy Analysis as Policy Advice. In *The Oxford Handbook of Public Policy*, ed. Michael Moran, Martin Rein, Robert E. Goodin, 152-168. New York: Oxford University Press.

Wu, Y., Welch, E. W., & Huang, W.-L. (2015). Commercialization of university inventions: Individual and institutional factors affecting licensing of university patents. *Technovation, 36-37*, 12-25. doi:10.1016/j.technovation.2014.09.004

York, A. S., & Ahn, M. J. (2012). University technology transfer office success factors: A comparative case study. *International Journal of Technology Transfer and Commercialisation* (1/2). Retrieved from https://www.researchgate.net/profile/Mark\_Ahn2/publication/264820471\_University\_technology\_transfer\_office\_success\_factors\_a\_comparative\_case\_study/links/5629991508aef25a243d818f/University-technology-transfer-office-success-factors-a-comparative-case-study.pdf

Appendix A. Tables and Figures

Table 1   
Federal Obligations to Universities for Research and Development

(Millions Nominal U.S. Dollars)



Table 2   
Federal Policies Related to University Technology Transfer

| Year | Policy | Relevant Provisions | Relevant Market Failures |
| --- | --- | --- | --- |
| 1980 | Pub.L. 96-517  Bayh-Dole Act | Permitted universities, nonprofit firms, and small businesses to take title to inventions derived from federally-funded research as a way incentive these organizations to facilitate the use of the inventions to benefit the public interest. | Public goods  Incomplete markets |
| 1980 | Pub.L. 96-480  Stevenson-Wydler Technology Innovation Act | Mandated that federal laboratories establish an Office of Research and Technology Application (ORTA) to facilitate their active technical cooperation with the private sector. | Imperfect information |
| 1982 | Pub.L. 97-219  Small Business Innovation Development Act | Mandated that federal agencies set aside a specific portion of their extramural research budgets to fund research and development projects within the scope of their agency missions to be performed by small businesses in the private sector. | Imperfect information  Imperfect competition  Negative externalities |
| 1984 | Pub.L. 98-462  National Cooperative Research Act | Enabled private sector businesses to enter into joint pre-competitive research and development ventures without violating federal antitrust laws. Eliminated treble damages in antitrust litigation arising from such ventures. | Public goods  Free rider problems  Imperfect information |
| 1986 | Pub.L. 99-502  Federal Technology Transfer Act | Established the Federal Laboratory Consortium (FLC) for Technology Transfer and enabled government-owned, government-operated federal laboratories (GOGOs) to directly enter into cooperative research and development agreements (CRADAs) with private sector businesses. | Information failures |
| 1987 | Executive Order 12591 | Further specified  Pub.L. 99-502 for administrative purposes. | Information failures |
| 1987 | Executive Order 12618 | Further specified  Pub.L. 99-502 for administrative purposes. | Information failures |
| 1988 | Pub.L. 100-418  Ominbus Trade and Competitiveness Act | Established Manufacturing Technology Centers and designated the National Institute of Science and Technology (NIST) as the lead agency to administer them. | Information failures |
| 1989 | Pub.L. 101-189  National Competitiveness Technology Transfer Act | Extended the ability to enter into CRADAs with private sector businesses to all government-owned contractor-operated federal laboratories (GOCOs). | Information failures |
| 1991 | Pub.L. 102-245  American Technology Preeminence Act | Authorizes appropriations to be available for Regional Centers for the Transfer of Manufacturing Technology, State Technology Extension Program, Advanced Technology Program, and Satellite Manufacturing Centers. | Incomplete markets |
| 1993 | Pub.L. 103-160  Defense Authorization Act | Directed the Advanced Research Projects Agency (ARPA) to promote dual-use technology via technology reinvestment. | Incomplete markets |
| 1995 | Pub.L. 104-113  National Technology Transfer and Advancement Act | Enacted changes to ease the ability of private sector businesses to obtain exclusive license to inventions that result from cooperative research with the federal government. | Incomplete markets |
| 2000 | Pub.L. 106-129  Technology Transfer Commercialization Act | Requires license applicants for federally-owned inventions to commit to achieving practical application of the invention within a reasonable time. | Negative externalities |
| 2011 | Pub.L. 112-29  Leahy-Smith America Invents Act | Reformed patent laws and instituted the “first inventor to file” patent registration system. | Free rider problems  Incomplete markets |

Table created by author.

Sources:

Feberallabs. (2013, December 23). *Technology Transfer Laws* [Video file]. Retrieved from https://youtu.be/k9CEPfku5DI

H.R.1249 - Leahy-Smith America Invents Act. (n.d.). Congress.gov. Retrieved May 20, 2020 from https://www.congress.gov/bill/112th-congress/house-bill/1249

H.R.1989 – American Technology Preeminence Act of 1991. (n.d.). Congress.gov. Retrieved April 23, 2020 from https://www.congress.gov/bill/102nd-congress/house-bill/1989

H.R.209 – Technology Transfer Commercialization Act of 2000. (n.d.). Congress.gov. Retrieved April 23, 2020 from https://www.congress.gov/bill/106th-congress/house-bill/209

Lee, Y. S. (1997). Technology transfer and economic development: A framework for policy analysis. In Y. S. Lee (Ed.), *Technology Transfer and Public Policy* (pp. 3-20). Quorum Books.

Table 3   
Determinants of Technology Transfer Outcomes Found in the Literature

Table 4   
NASA Technology Readiness Level Scale

Table 5   
Alternative Readiness Level Scales



Figure 1   
Federal Obligations to Universities for Research and Development, 2000-2019

Figure created by author.

Data source:

National Science Foundation, National Center for Science and Engineering Statistics [NCSES]. (2020). Survey of Federal Funds for Research and Development, Fiscal Years 2018-19. Retrieved May 7, 2020 from http://www.nsf.gov/statistics/fedfunds/