An Overview of the Policy Problem and Review of the Literature Related to a Proposed Study of the How Technology Maturity Level Influences the Technology Transfer Activities of   
Private Sector Organizations and the Implications for Public Policy

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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 since the 1940s. 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 several 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 and national security as desirable outcomes 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 technology maturity level in university technology transfer outcomes is among the gaps in the knowledge base. The potential role of technology maturity level 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 maturity level 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 maturity level, technology transfer, research and development, public policy

Chapter 1 – 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 years since the end of the Second World War. 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.

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 justify 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?, and (4) what should be the role of the government in university technology transfer? This introductory section defines the key constructs relevant to the proposed study and answers the study justification questions using the lens of public sector economics.

Motivation for and Purpose of the Proposed Study

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 a low percentage of technologies derived from federally-funded research and development (R&D) is successfully transferred to the private sector for use that benefits the public interest (Feibleman, 1961; Schact, 1998; Schact, 1999; Schact, 2012; Tseng & Raudensky, 2014). This is a policy problem that has challenged the U.S. government since the establishment of the modern R&D funding structure shortly after the end of the Second World War.

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 level of maturity 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 technology maturity level influences the likelihood that a technology will be successfully transferred to the private sector for use that benefits the public interest.

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 and which is embodied in such a manner to enable, hinder, or otherwise control its access and use. This definition is consistent with the observation of Lall (2001) that technology must be embodied in specific items as well as the notions of other scholars that have commented on the subject (see e.g., Herschbach, 1995; Leonard-Barton, 1990; Stoneman, 2002; Williams & Gibson, 1990).

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 known 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 the form of technology over time. 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 reveal 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 stable 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). United States 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 hierarchy 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. Frické argued that 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 further 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 associated with operationalizing the concept 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 only those 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 technology transfer seem to conflate it 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?

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. The literature provides ample evidence that university technology transfer satisfies this criterion.

Public sector economics also 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 proposed study has implications principally for the second and fourth questions, which are key components of any public policy decision.

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 of this policy history is that 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 final 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, for whatever reason, 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 activities, 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 (Figure 2a). Stokes demonstrated that this one-dimensional linear model is both inadequate and inaccurate in describing reality. Figure 2b depicts a model that is more probably representative of the actual nature of technological advancement.

The Notion of Technology Maturity Level

The notion of technology maturity level seems to have crystallized in the United States in the 1970s in connection with the federal government’s management and implementation of financially expensive complex technological systems for high risk endeavors. The managers for such programs used the construct to better mitigate over budget expenses, deficient performance, and potential project cancellations caused by delays in when components would be ready for integration into the broader systems (Mankins, 2009; Olechowski, Eppinger, & Joglekar, 2015).

The construct of technology maturity level is difficult to define. Nolte (2008) resorted to analogies and scenarios to try to explain technology maturity level but never provided an exact definition. His concept of technology maturity level is inextricably tied to his definition of technology, which is instrumental. Based on the discussion that Nolte offered, I propose that technology maturity level can be defined as the degree to which one can use a technology to achieve a desired outcome that is acceptable.

It is worth noting that technology maturity level has the characteristics of value neutrality, context dependency, and multi-dimensionality (Nolte 2008). Technology maturity level is neither “good” nor “bad” in and of itself. One’s assessment of whether a given technology maturity level is acceptable depends entirely on the context in which one is using the technology. Moreover, a comprehensive assessment of technology maturity level requires an examination from multiple perspectives.

Technology maturity level 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. According to Blank and Dorf (2012), there are two primary types of risk that technology maturity level needs to describe. They 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. Nolte (2008) argued that there were at least four dimensions of technology maturity level comprising technical, programmatic, developer, and customer viewpoints. 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 calls this into question.

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 operationalizing technology maturity level 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. 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 technology maturity level has also taken hold in the field of technology transfer. Spearman (2013) specifically used the concept of TRLs to describe technology maturity level 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 technology maturity level 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).

Reflecting on the literature raises the question of whether technology maturity level explains to any degree the low percentage of technologies derived from federally-funded R&D that are successfully transferred to the private sector for use that benefits the public interest. The answer to this question has implications for public policy regarding technology transfer in general and university technology transfer in particular.

Approach to Examining the Topic

Under the current framework for university technology transfer, private sector organizations are presumed to be the consumers of university-created technologies (Table 2). This includes entrepreneurs who will need to develop organizations to successfully leverage the technologies they acquire to create value and build wealth. As such, 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. Policies are often designed to influence the behaviors of private sector organizations, such as profit-seeking business firms (Cyert & March, 1963, p. 269), as well as individuals. As such, how private sector organizations function needs to be considered when crafting public policy regarding university technology transfer. Therefore, the proposed study focuses on how technology maturity level influences the technology transfer priorities, intentions, and actions of private sector organizations that are likely to participate in the university technology transfer process.

In the next chapter, I summarize the related literature to explain how technology maturity level has been approached in the context of university technology transfer. This will help to better isolate the research question and inform the research design for the proposed study.

Chapter 2 – Review of the Related Literature

technology maturity level 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 institutions sponsoring the research, which can push aside 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 the technology transfer process.

Technology Maturity Level as an Understudied Explanatory Factor

In my review of the literature, I found only one study that specifically investigated the association between technology maturity level 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 and using inventions to operationalize the concept of technology, 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 (2012) does not specifically answer the research question of the proposed study. If we take the results at face value, they only posit an explanation for the distribution between established firms and startup firms of university technologies transferred to the private sector. It does not explain why the overall percentage of university-created technologies that are transferred to the private sector is low compared to policy expectations. Moreover, there are several issues with the approach Munteanu used that the proposed study addresses. I explore these issues in detail in a later section of this chapter.

technology maturity level outcomes

technology maturity level technology maturity level technology maturity level outcomes

Technology maturity level has not been extensively investigated as a determinant of technology transfer outcomes.

However, the broader literature provides evidence to suggest that technology maturity level plays an important role in successful university technology transfer. A key argument 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 is 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) was the only literature I found where technology maturity level was explicitly considered in the study of technology transfer outcomes. There is literature that discuss the technology readiness level (TRL) scale as a measure of technology maturity level (see, e.g., EARTO, 2014; Estep, 2017; 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 technology maturity level in university technology transfer.

The insights offered by Stokes (1997) have significant implications for examining the potential role of technology maturity level 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 (Figure 2a). 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 (Figure 3).

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.

Technology Maturity Level and Technology Transfer Outcomes

Based on my professional experience and review of the literature, I hypothesize that technology maturity level helps explain why the percentage of university-created technologies derived from federally-funded research and development that is transferred to the private sector for use that benefits the public interest is low. While the technology transfer literature that explicitly examines the role of technology maturity level in university technology transfer is sparse, various scholars have explored the issue around its periphery under various monikers and in different ways.

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 technology maturity level 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 (Figure 4). Many of these studies seem to allude to an association between technology maturity level 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 maturity level 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 is strong *prima facie* evidence in support of the hypothesis that technology maturity level 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). Technology maturity level 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 technology maturity level, such as technology category, is the primary determinant between those technologies that successfully cross the “valley of death” and those that don’t.

The Perspectives of Organization Studies and Decision Theory

The literature suggests that the path to a better understanding of the underlying phenomenon and crafting more effective technology transfer policy is through an examination of the issue from the perspective of private sector organizations using the lenses of organization studies and decision theory. 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.

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.

Decision Premises and the Actions of Organizations

The quest to understand the role that technology maturity level plays in determining whether organizations pursue, acquire, and use technologies created by universities in many respects is an exercise in understanding a specific type of organization behavior. Simon (1997) offers a very useful framework for accomplishing this end.

Simon (1997) argued that the essential activities of an organization are physical tasks (i.e., actions) deemed necessary to achieve the objectives of the organization. These tasks are performed by the operative members of the organization who typically occupy the lower level positions of the organizational hierarchy. The role of organization members occupying positions at higher levels of the hierarchy often involves making decisions that are not tied to a physical action but instead are primarily meant to guide the actions of members at the lower operative levels of the organization.

Before a physical action is performed by a member of the organization there must be a decision to perform the action. Every action involves a decision about whether to act and what action among multiple alternatives to take if action is in fact warranted. Therefore, the operative activities of an organization can be conceptualized as a series of decision-action couplets. Since every organization action is associated with a decision and decision making pervades all levels of an organization, focusing on the decision-making process is a viable approach to understanding the behavior of groups in an organizational context.

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). If the goal is to implement policy that produces desired outcomes, then policymakers must act in accordance with the world as it is, not as academics believe it should be. Consequently, the proposed study is more descriptive and focused on how organizations actually make decisions rather than a normative approach seeking to specify how they should make decisions.

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. It is important to understand how organizational decision-making may differ from individual decision-making which will likely provide insight into the role of technology maturity level in organizations’ decisions about the acquisition of technology. However, the psychology of individual decision making is still necessary to understand organization decision making. It is not a matter of either a sociological perspective or a psychological perspective. Asking whether organization decision making is socially-driven or psychologically-driven is like asking whether molecular biology is chemistry or biology. Molecular biology is both chemistry and biology. Likewise, organization decision making is both sociological and psychological (Simon, 1997).

According to Simon (1997), humans make decisions in an organizational context based on beliefs about the nature of the physical and social world and their perceptions of the way things "ought" to be. Every decision made by organization members is composed of two distinct types of beliefs. The first type of belief is factual propositions which one can empirically determine to be true or false in an absolute sense. The second type of belief is value propositions which one cannot empirically determine to be true or false in an absolute sense. The factual and value propositions one uses to arrive at and justify a decision to take an action are called decision premises.

In the framework outlined by Simon (1997), one could argue that factual premises are rooted in data and information while value premises are rooted in emotions and preferences. Value premises are essentially imperative declarations that select one possible future state as desired and thereby exclude all others. Value premises are beliefs about the way things "ought" to be. They are ethical or normative in nature (Simon). Many decisions of organization members in roles at the higher levels of an organization hierarchy are nothing more than value premises meant to guide the decisions and actions of members in roles at lower levels in the organization hierarchy.

Simon (1997) points out that most ethical propositions are intertwined with factual propositions. Therefore, most value premises are intertwined with factual premises. One cannot derive factual premises from value premises or vice versa. Trying to compare factual propositions to value propositions is tantamount to comparing apples and oranges.

Some of the nomenclature that Simon (1997) uses is a bit confusing. In the ordinary use of the term “factual” tends to mean that a statement or assertion is true in an absolute sense. However, in framework described by Simon, factual propositions are not necessarily true although they can empirically be determined to be true or false in an absolute sense. As such, a factual decision premise can be either true or false, accurate or inaccurate. Given that factual premises are rooted in data and information, it seems more appropriate and less confusing to use the term knowledge propositions or knowledge premises, which is the term I shall use going forward.

The term knowledge premise is also better aligned with the DIKW hierarchy. Each element of the DIKW hierarchy incorporates the elements below it. Knowledge builds upon data and information, which I previously noted roots factual premises. Since both data and information can be incorrect, inaccurate, or incomplete so too can knowledge. Therefore, knowledge decision premises may be either true or false in an absolute sense.

Organization decision making is often an exercise in complex decision making in that the ultimate decision being made requires multiple antecedent decisions. A decision at any given point in time may require a series of antecedent decisions that function as decision premises the ultimate decision to be made along with other value and knowledge premises. Moreover, the decisions made by a person in one part of an organization may serve as decision premises for other persons in other parts of the organization.

Simon (1997) describes organization decision making as a “decision-fabricating process” (p. 24). In some ways, this is analogous to formulating an argument, by which I am referring to a line of reasoning to support a position, claim, or conclusion. Natural language arguments, as described by Fisher (2004), are created by combining independent reasons, compound reasons, and necessary intermediate conclusions to provide the justification for a main conclusion. The veracity of only one of several independent reasons is enough to justify a conclusion while the veracity of all compound reasons must be established to justify a conclusion. Likewise, organization members combine value and knowledge decision premises (including antecedent decisions serving as decision premises for subsequent decisions) in a Boolean fashion to guide the decision-making process and produce a given organization decision.

The ultimate decisions of organizations regarding technology transfer opportunities are likely complex decisions requiring several antecedent decisions. Moreover, it’s likely that at least some of the decision premises (including antecedent decisions serving as decision premises for subsequent decisions) are compound premises meaning that all premises are required to justify the action. If technology maturity level is a factor in the decisions of private sector organizations not to acquire any given university-created technology, it probably manifests as a decision premise in either the ultimate decision or an antecedent decision. Moreover, technology maturity level alone will be sufficient to produce a decision not to pursue a university technology transfer opportunity if it is part of a set of compound decision premises for any decision point in the decision chain.

There are multiple points in the organization decision making process about technology transfer opportunities where technology maturity level may in fact be a decision premise. At the most basic level, organization decision-making involves setting the agenda, representing the problem, finding alternatives, and selecting alternatives (Simon, 1997). This process is not necessarily linear and is more likely to be iterative. Technology maturity level likely surfaces as a factor in organization decision-making about technology transfer opportunities during the alternatives search and selection phases of the decision-making process.

Agenda setting refers to selecting the items on which to focus the attention of organization decision makers (Simon, 1997). Acquiring university-created technologies can come to be considered for the agenda of decision makers through either an internal signaling system or a sensory mechanism triggered by the external environment. An example of an internal signaling system would be the number of research and development (R&D) or new product development (NPD) projects in queue. The organization members responsible for these activities might establish a target for the number of such projects in queue, which would essentially act as an “order point.” A signal would be sent to the appropriate organization members when some level of deficit in the number of projects in queue is reached thus placing the need to acquire university-created technologies on the organization agenda. Technology maturity level may serve as a decision premise that guides which types of technologies would be considered for acquisition to restore the number of projects in queue to desired target levels. In this case, the organization might establish that only technologies that have reached a given technology maturity level shall be acquired. This would be a value decision premise and would act as a constraint to guide the decisions of organization members responsible for restoring the number of projects in queue to desired target levels. In the absence of such value premises, technology maturity level might surface as a knowledge decision premise that the organization members use to formulate their decisions about which technologies to consider for acquisition to restore the number of projects in queue to desired target levels. An example of such a knowledge premise would be “the organization has more success with technologies that have reached at least a form-and-function prototype stage.” The veracity of this premise could be empirically determined.

Technology scouting would constitute an example of a sensory system triggered by the external environment. In many organizations, individuals are charged with scanning the external environment for opportunities to acquire university-created technologies. Specific university technology transfer opportunities only reach the organization agenda if the individuals charged with scanning the environment come across a technology and decides to place it on the decision agenda of the organization. Technology maturity level may constitute one of the decision premises that these individuals use to determine whether to put a given technology forward as an alternative for the organization’s consideration. This could be a value premise such as “the organization shall only consider technologies for new therapeutics for which there is data available from *in vivo* testing” or a knowledge premise such as “the organization has never previously licensed any university technology for which there was not data available from *in vivo* testing.” The former is an imperative statement for which true or false is meaningless. The veracity of the latter can be evaluated empirically.

**Organization Decisions About University Technology Transfer Opportunities**

Because of the decision-action coupling described above, one can begin to identify the various decisions that an organization must make in choosing to pursue, acquire, and use a given university-created technology by considering the specific actions that the organization must take to fulfill such a choice. Broadly speaking, these actions include …

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?

Uncertainty Avoidance in Organizations

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.

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).

Technology Maturity Level in Federal Technology Transfer Policy

Federal technology transfer policy does not explicitly and directly address technology maturity level but there are aspects that one can use to draw some conclusions about the role of technology maturity level 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 technology maturity level 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 technology maturity level. 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 technology maturity level 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 technology maturity level.

Concluding Remarks

This literature review sought to identify the relevant conceptual and theoretical frameworks for a proposed study of the role of technology maturity level 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 maturity level 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 technology maturity level, evidence suggesting the potential influence of technology maturity level on the university technology transfer process, and whether and how technology maturity level 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 technology maturity level 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 technology maturity level in university technology transfer outcomes.

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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.

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Table 3  
Determinants of Technology Transfer Outcomes

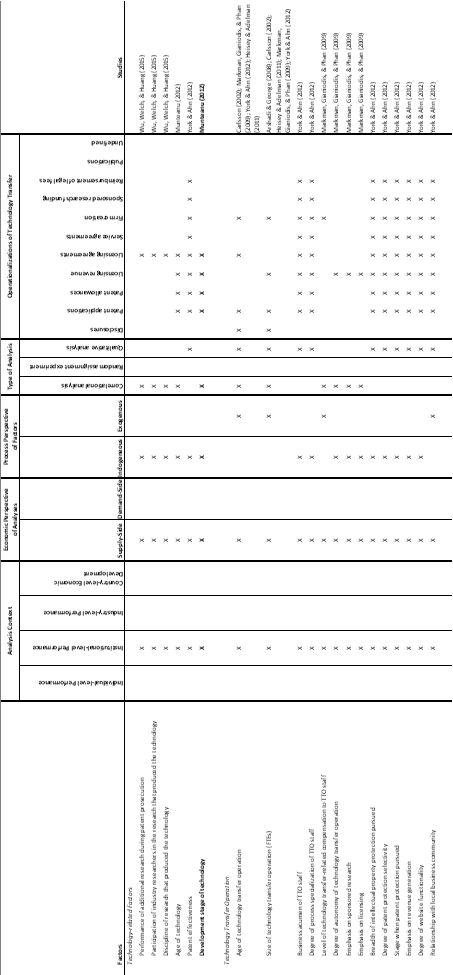


Table 3.

*Determinants of Technology Transfer Outcomes Found in the Technology Transfer Literature*



Table 3 (continued).

*Determinants of Technology Transfer Outcomes Found in the Technology Transfer Literature*



Table 3 (continued).

*Determinants of Technology Transfer Outcomes Found in the Technology Transfer 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/

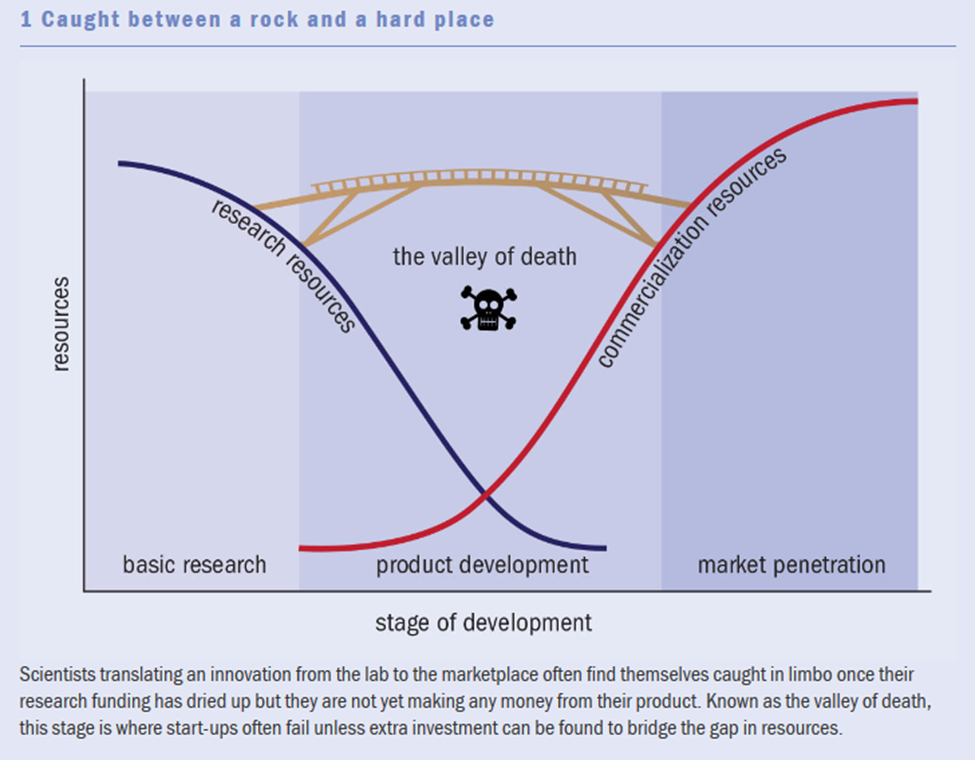
Figure 2   
The Relationship between Research and Societal Benefits



Figure 3  
Stokes Four-Quadrant Model of Scientific Research



Figure 4  
The Valley of Death



Dacey, J. (2014). Navigating the valley of death. *Physics World, 27*(11), 29.