1. Introduction

The difference between the almost right word and the right word is really a large matter—'tis the difference between the lightning bug and the lightning.
Mark Twain

Reflecting on the wisdom of Mark Twain in the epigraph above, perhaps there are some phrases and terms that should initially be defined at the beginning of this book (or, as a matter of fact, at the beginning of most books). The four phrases and terms to be defined—and they are not independent of each other—are *technology transfer*, *public sector*, *innovation*, and *public sector innovation*. We belabor a discussion of these four phrases and terms in this first chapter in an effort to clarify the topics that we will, and will not, discuss in the pages that follow.

Our purpose, for what some might consider to be a *terminology prologue*, is not intended to redefine any phrases or terms that are well known to the reader from the relevant literatures; rather our purpose is intended to help to ensure consistency for the reader's interpretation of our themes, as well as to our policy arguments and recommendations, keeping in mind that much of the empirical analysis in this book is exploratory in nature as will be emphasized throughout. As we mention throughout this book, especially in the academic and policy literature reviews in later chapters, there is a conspicuous lack of systematic empirical analysis of US technology transfer mechanisms in federal laboratories and agencies due to, or so we conjecture, the lack of access to laboratory-by-laboratory or agency-by-agency data.[1]

DEFINING KEY PHRASES AND TERMS

Technology transfer has long been a topic of interest to scholars and practitioners who study research and development (R&D) investments. This is the case for investigations into R&D funded by as well as performed by firms and agencies in both the private and public sectors. Often, these studies focus on the development of a variety of technologies that, when transferred to or within sectors, lead to innovations. The idea behind our discussion of these two issues—development of and transfer to or

within—is straightforward and, in a sense, linear in its logic. Stated more succinctly, investments in R&D lead to new technologies, and some of those technologies are transferred through various technology mechanisms and activities to the private sector and within the public sector; and, as a result, they are then referred to as innovations. From a symbolic perspective:

$$\text{R\&D} \rightarrow \text{technology} \rightarrow \text{transfer} \rightarrow \text{innovation}$$

Among the many topics that have been frequently discussed with reference to this so-called linear representation of a model are:

- What is the optimal level of public sector R&D?
- Can the efficiency of the transition from investments in R&D to activities related to the adoption and the development of new technologies be measured?
- Can the transition from investments in R&D to activities related to the adoption and the development of new technologies be made to be more efficient?
- Which technologies are effectively commercialized to become innovations, and why?

The Federal Laboratory Consortium (FLC) for Technology Transfer (FLC, 2013, p. 3) offers a definition of the phrase *technology transfer* which we use here as a starting point for our discussion in this chapter (and which is also the topic theme of this book). This definition is more general than the representation of the linear representation of the R&D to innovation model above; this definition transcends intermediate steps and simply addresses the process of going from R&D to innovation:

> There are many definitions of technology transfer, but at its most basic level technology transfer is generally considered the process by which technology or knowledge developed in one place or for one purpose is applied and used in another place for the same or a different purpose. This broad definition covers a wide variety of procedures or mechanisms that can be used to transfer technology and is not necessarily restricted to federal [or even public sector] activities.

Relatedly, the National Institute of Standards and Technology (NIST) defines technology transfer as:[2]

> NIST broadly defines technology transfer as the overall process by which NIST knowledge, facilities or capabilities in measurement science, standards and technology promote U.S. innovation and industrial competitiveness in order to enhance economic security and improve quality of life.

In recent decades, partly in response to the productivity slowdown in the United States in the early 1970s and again in the late 1970s and early 1980s, which we discuss in some detail in later chapters, Congress focused on mechanisms for transferring technologies funded by the public sector to the private sector and to other organizations. Although, Congress as part of that discussion did not explicitly define the phrase *technology transfer*. For example, Congress passed the Stevenson-Wydler Act of 1980 (Public Law 96-480) in October of that year. Congress stated in that legislation in Section 2 of the Act:

> The Congress finds and declares that . . . No comprehensive national policy exists to enhance technological innovation for commercial and public purposes. There is a need for such a policy, including a strong national policy supporting *domestic technology transfer* [emphasis added] and utilization of the science and technology resources of the Federal Government.

In Section 4 of the Act, Congress defined a number of key phrases and terms germane to the implementation of the Act, but it excluded from the list the phrase *technology transfer*. Thus, for the purposes of clarification, and for the purpose of focusing on the subject matter and topics in this book, one might interpret the phrase *technology transfer* from the perspective of the public sector as the transferring entity in the following way (FLC, 2013, p. 3).

> Technology transfer is the process by which existing knowledge, facilities, or capabilities developed under federal research and development (R&D) funding are utilized to fulfill public and private needs.

Important to note in this definition offered by the FLC, an organization that will be discussed in a later chapter, is the emphasis on R&D funding as being a genesis element or a catalyst of what is ultimately transferred through an appropriate mechanism. Also, it is important to note what technology is being transferred. The technology or transfer object is broader in its scope than a physical technology. Technology also includes technical knowledge and capabilities which are intangible technology elements. Technical knowledge can be tacit or codified (literally, or figuratively when embodied in a physical technology) in its nature.

The term *federal* is used in this FLC definition, but we used the phrase *public sector* in the title to this book. Of course, the phrase *public sector* refers to the part of an economy which is controlled by a governmental body. We are using that phrase *public sector* in the title to this book, and in much of the discussion in later chapters, to refer to the federal government as opposed to the state or local governments. Our focus is

on knowledge, technology, and innovation funded by and developed in the public sector that is transferable to private sector firms and to other organizations.

Also, throughout this book we will attempt to be deliberate in our use of the phrase *federal laboratory* and the phrase *federal agency* (US Code, Title 15, Chapter 63, § 3703).[3]

> Federal laboratory means any laboratory, any federally funded research and development center, or any center . . . that is owned, leased, or otherwise used by a Federal agency and funded by the Federal Government, whether operated by the Government or by a contractor . . . Federal agency means any executive agency . . . as well as any agency of the legislative branch of the Federal Government.

The phrase *federal laboratory* is relevant for our descriptions of federal technology policy and for the reviews of the various contributions to existing academic and policy literatures that we present and summarize in later chapters.[4] The technology transfer metrics (i.e., data) that we present and analyze in later chapters are at the federal agency level; that is, the data are federal laboratory technology transfer metrics that are aggregated to the level of the federal agency in which the laboratories reside.

A word about the term *innovation* (noun). According to the Etymology Dictionary, the word *innovate* (verb) traces to the 1540s.[5] Its origin is the Latin word *innovates* meaning to introduce as new. An innovation, from the Latin word *innovationem*, refers to what is introduced as new.[6] Leyden and Link (2015) refer to an innovation in a codified sense as a technology put into use. Thus, in their terms, when a newly developed or modified technology is commercialized, and thus put into use, it is referred to by the term *innovation*. Because the subject matter in this book is related to federal technology transfer policy and practice, we will use the term *innovation* to refer to the output of federal R&D, generally from R&D conducted in a federal laboratory, be it knowledge *per se* or a new or modified technology that is put into use.

PUBLIC SECTOR INNOVATION

Our use of the phrase *public sector innovation* in the title to this book may unintentionally give pause to some scholars in several fields of study such as public administration and public policy. To some, especially in these two fields, and possibly in economics and more, the phrase *public sector innovation* might have a specific meaning (and we certainly do not challenge that meaning herein).[7]

According to the European Commission (2013, p. 12): "A [public sector] innovation is a new or significantly improved service, communication method, process or organizational method." Or, according to Mulgan (2014, p. 5): "Put simply, public sector innovation involves creating, developing and implementing practical ideas that achieve a public benefit."

Similarly, according to OECD (2017, p. 11): "Public sector innovation is about finding new and better means to achieve public ends." And, innovation in the public sector has three defining characteristics (OECD, 2015, p. 14):

> Novelty: Innovations introduce new approaches, in the context where they are introduced.
> Implementation: Innovations must be implemented, not just an idea.
> Impact: Innovations aim to better public results, including efficiency, effectiveness, and user or employee satisfaction.

To expand on these three characteristics, we refer to Clark, Good, and Simmonds (2008). These scholars offered the following typology of innovation in the public sector, where the drivers of public sector innovation are political push, pressure for economy and improved efficiency, and pressure for improved service quality. In their model, R&D investments are not the, or even a, driver of public sector innovation. More specifically, the Clark et al. (2008, p. 5) drivers are:

> New or improved service: for example home-based care for the elderly.
> Process innovation: a change in the manufacturing of a service or product.
> Administrative innovation: for example the use of a new policy instrument, which may be a result of policy change.
> System innovation: a new system or a fundamental change of an existing system, for instance by the establishment of new organizations or new patterns of cooperation and interaction.
> Conceptual innovation: a change in the outlook of actors; such changes are accompanied by the use of new concepts, for example integrated water management or mobility leasing.
> Radical change of rationality: meaning that the world view or the mental matrix of the employees of an organization is shifting.

Our interpretation of the above definitions and characterizations of public sector innovation is that the public sector is being viewed as the consumer of its own innovation, where such innovation is intended to be a "means to achieve public ends" (OECD, 2017, p. 11). However, in this book we attempt to expand on the concept of public sector innovation by emphasizing that achieving "public ends" can more broadly be thought of to include the private sector being the consumer of the public sector's innovation—not a consumer of a public sector's service, organizational,

or administrative innovation but rather a consumer of a knowledge-based technical innovation, meaning that when a knowledge-based technical innovation is consumed in the private sector that process will generate important social value.

Along similar lines, Kay and Goldspink (2016, p. 4) emphasize motivational differences to innovate between the public sector and the private sector:

> The public sector is innovative, but the nature and form of that innovation is different to the private sector, and arises from fundamental differences in the two sectors' measures of success. The market provides the private sector with a greater range of possibilities to extract reward from the risks it takes. The private sector can undertake a portfolio approach to this risk, on the basis that it can 'net out successes and failures.' The failed ideas can often have limited downside, and can be compensated (financially) through the success of other ideas, such that on balance the organisation comes out ahead. While stakeholder related risks exist for the private sector, it can be argued they have less impact than in the public sector. . .

Broadening the emphasis of public sector innovation to include the private sector as a consumer of knowledge-based technical goods funded by and produced by the public sector does not change the fact that innovation in the private sector is motivated "to achieve competitive advantage in the market to support profit generation" (OECD, 2015, p. 14). In contrast, public sector innovation is motivated, in view of those scholars who we quoted above, by achieving the elements in the innovation drivers' typology referenced above.

Our emphasis in this book is on public sector R&D resulting in technologies transferred from federal laboratories or agencies—in the form of tacit knowledge, as well in the form of codified knowledge that is manifested as a new or modified technology or even as an innovation from the public sector (i.e., a public sector innovation)—and later being observed in use in both the public sector and/or the private sector. Our emphasis on innovation originating in the public sector from its R&D investments, but having applications elsewhere, perhaps broadens an understanding of the public sector being more than a sector simply to achieve "public ends" that "achieve the desired public outcome" (OECD, 2015, p. 14). Our emphasis on public sector R&D facilitates an understanding about a path through which the public sector can over time promote technology-based economic growth and development above and beyond what the private sector would achieve in the absence of public sector action.

REDEFINING TECHNOLOGY TRANSFER

We will use throughout this book the phrase *technology transfer* in the following way. Our use of the phrase refers to the transfer of knowledge-based technology, generated in the public sector through federally funded R&D, to the private sector, or to other parts of the public sector. Our use of the phrase *technology transfer* requires an understanding of several additional concepts. The first concept is *technology*, and we made reference to it above. Our definition of the term *technology* is also interdependent with the following definition of the terms *science* and *innovation*:

- *science*—the search for new knowledge; the search is based on observed facts and truths; science often begins with known starting conditions and searches for new understandings
- *technology*—the application of knowledge, learned through science and the interaction of science and technology, to some practical problem
- *innovation*—technology that is put into use or commercialized.[8]

To repeat, fundamental to our discussion of the term *technology* is that technology, as the application of knowledge, does not necessarily need to take a physical form. Technology can also be embodied in processes in the form of technical knowledge, and that knowledge might be tacit in its nature or codified in, say, scientific publications. Thus, one might reasonably think of technology in period t as knowledge that eventually becomes embodied elsewhere in a physical representation of scientific facts and truths in period $(t+1)$. What is important is that our focus in this book is primarily on federal technology transfer. And, to tie our discussion to our effort to broaden the concept of public sector innovation, we emphasize that the technologies that we focus on that are being transferred elsewhere originated in the public sector (i.e., a national government sector but the broad notion applies to state and local government as well) and are aimed for use in the private sector or perhaps in other areas of the public sector. Our emphasis on "primarily," with reference to federal technology transfer in a previous sentence should not be overlooked. While the majority of the remaining chapters in this book do focus on federally funded technology developed in federal laboratories and agencies, we also will point out, and discuss at some length in a later chapter, that a complete discussion of federal technology transfer might reasonably include federally funded technology that is developed in the private sector and transferred from there to other areas of the private sector or even to the public sector.

As an aside, one might extrapolate from the above discussion and think of technology in period ($t=1$) becoming embodied in the development of a new technology in period ($t=2$), and so on. In fact, Arthur (2009) makes the point that continued public sector and/or private sector investments in R&D are important for continued economic growth because new technologies that emanate from these R&D investments are simply combinations of previous technologies that have developed from previous R&D investments. One might even think of Arthur's argument in terms of a Matthew Effect (Merton, 1968). It is important that a nation continually grows its technical knowledge base because breakthrough technologies do not fall like manna from heaven. Rather, they have at their origin the accumulation of the knowledge base relied on for and from previous technologies.

With this concept of technology in mind—the application of new knowledge, learned through science and the interaction of science and technology, to some practical problem—and with our segue from the traditional definition of public sector innovation to the concept of federal technology transfer, we assert that technology can be transferred from federal laboratories or agencies in one of two ways. (And, to repeat, we have in mind US federal laboratories throughout this book, but of course that conceptualization can be broadened; thus, we delete the adjective *US* hereafter when referring to federal laboratories.) Technology can be transferred in an explicit or codified form, that is as a physical technology (e.g., as standard reference material), or it can be transferred in an implicit or tacit form that embodies technical knowledge (e.g., working with scientists through a Cooperative Research and Development Agreement, or CRADA). Again, technology as knowledge can be transferred from federal laboratories in both a codified form and in a tacit form.

We discuss throughout this book various mechanisms through which technology has been and will likely continue to be transferred from federal laboratories and agencies. Of course, technology can meaningfully be transferred from other sources, such as universities, domestic firms, and international firms and organizations through a variety of mechanisms thus forming a network of technology transfer. But, herein we primarily focus specifically on technology that is transferred from federal laboratories and agencies, and, more specifically, we focus primarily on those public policies that initiated such technology transfers.[9]

As a starting point, having defined the term *technology* and the phrase *technology transfer*, and having suggested that technology can be transferred through a number of different mechanisms, we introduce the remainder of this book with a discussion of the origin of the idea or concept of technology transfer. This historical emphasis, we believe, gives

context for the argument that technology transfer *per se* is not an activity of recent decades, although in the United States public policy to enhance technology transfer is an action that has gained significant attention in recent decades.

Many date the genesis of scholarly studies of technology transfer from US federal laboratories with the passage of the Stevenson-Wydler Act of 1980, which we discuss in Chapter 2. However, Moy (2014) dates the first US patent from a federal laboratory to 1923. In Chapter 2, we argue that the origins of US technology transfer even predate any patenting history from a federal laboratory or agency. Thus, the study of technology transfer from federal laboratories and agencies should not, in our view, be justified only in terms of a response to any specific policy or policies; but rather, the study of technology transfer should be thought of in terms of purposeful activity by the public sector to "promote the general Welfare." The Preamble to the Constitution of the United States reads:

> We the People of the United States, in Order to form a more perfect Union, establish Justice, insure domestic Tranquility, provide for the common defence [sic], promote the general Welfare, and secure the Blessings of Liberty to ourselves and our Posterity, do ordain and establish this Constitution for the United States of America.

OUTLINE OF THE BOOK

The remainder of this book contains topic-focused chapters. Some of the chapters are long and some of the chapters are short; some of the chapters are based on a description of public domain data and some of the chapters are exploratory policy-related essays and/or statements written within a Mansfieldian tradition.[10] Our goal in each chapter is to address a specific topic or idea without regard for balance among chapters in terms of words, pages, tables, or figures. This description of the chapters that follow does not mean that the chapters are unrelated. On the contrary, we have attempted to tell an integrated story about technology transfer and US public sector innovation by building on elements from the relevant literatures and empirical descriptive analyses. The chapters that follow are our collection of opuscula. They are definitely interrelated, and they are presented in a manner that integrates the themes of this book.

In Chapter 2, we offer an historical context for the concept of technology transfer in general, with a particular emphasis on the importance of technology transfer for the betterment of a nation.

Then, in Chapter 3, we provide a legislative overview of US public policies to encourage the transfer of federally funded technologies from federal

laboratories and agencies in an effort to bound our subsequent discussion of technology transfer mechanisms and metrics. The policy specifics of this discussion begin with the Stevenson-Wydler Act of 1980. This 1980 Act was one of many initiatives that were promulgated late in that year, and in the years that soon followed. These initiatives were part of a collective policy response to the so-called US productivity slowdown that began in the early 1970s and then again in the late 1970s and early 1980s (Leyden and Link, 2015). While the focus of this book is on federal laboratory and agency technology transfer, we include a brief discussion in Chapter 5 about other policies that, like the Stevenson-Wydler Act of 1980, were a response to the productivity slowdown.[11]

In Chapter 4, we offer a discussion that we couch under the heading of *the economics of technology transfer*. Perhaps readers will consider the arguments in this chapter as having some elements of a theoretical or conceptual foundation useful for a more in-depth understanding of the economics-related elements and consequences of technology transfer. Our theoretical discussion might offer an economics-based insight into public policies that are focused on technology transfer as well as a perspective about the economics-related impacts of successful technology transfer and how those impacts affect the performance of the adopting firm or organization.

In Chapter 5, we explore empirically the effectiveness of US technology transfer policies that begin in the 1980s. Here, we summarize various public policies enacted in response to the productivity slowdown with an emphasis on technology transfer policies. Then, we estimate the correlations between aggregate productivity growth and federal R&D expenditures in the pre- and post-Stevenson-Wydler Act and pre- and post-Federal Technology Transfer Act periods.

Following this legislative overview and related analysis, we summarize in Chapter 6 the existing academic and policy literature on technology transfer from federal laboratories and agencies. Our conclusion from these literature reviews is that the academic and policy research on technology transfer from federal laboratories and agencies is thin, and we suggest that a possible reason for this is the lack of accessibility to granular data about technology transfer mechanisms developed in and transferred from federal laboratories and agencies.

In Chapter 7, we present what we believe is that population of public domain aggregated data on technology transfer metrics from federal laboratories and agencies (e.g., inventions disclosed, patents, licenses, and CRADAs). We report in this chapter agency-level data in tabular form not only for completeness but also to encourage others to study them in detail. We also describe these data graphically in terms of trends in the use of

several technology transfer mechanisms, and we approximate statistically how the numerical representation of these mechanisms has changed over time when aggregated across agencies.

In Chapter 8, we disaggregate our discussion of aggregated technology transfer activity, and we focus on the same technology transfer mechanisms and metrics as in Chapter 7, but at an agency-specific level. Our methods of analysis remain the same as in Chapter 7, but our agency-level analysis allows us to emphasize, in what we believe is a meaningful way, across agencies differences in the intensity of technology transfer activity over time. Keeping in mind that the metrics associated with the various technology transfer mechanisms are at the agency level (i.e., the metrics are the aggregation of metrics from agencies' various laboratories on selected technology transfer mechanisms), we are unable to describe laboratory-by-laboratory trends in various technology transfer mechanisms. However, it should not be assumed that the cross-laboratory trends in any particular mechanism are the same even within a particular agency.

Chapter 9 presents agency-provided examples of successful technology transfers. We include these examples in an effort to provide an element of context or reality to the technology transfer activities described and analyzed quantitatively throughout this book.

In Chapter 10, we use agency-specific technology transfer metric data, and other data, to estimate what we call a public sector knowledge production function. This analysis approximates one dimension of the impact of agency R&D expenditures on the production of technology-based knowledge as proxied by metrics associated with various technology transfer mechanisms.

Chapter 11 offers an exploratory representation of the broader impact of R&D spending in federal agencies. Our discussion emphasizes, from an historical perspective as well as from an empirical perspective, the following relationship:

R&D → New Inventions Disclosed → New Patent Applications → New Patents Issued → New Licenses

Each element or activity in this descriptive linear model will have been discussed in earlier chapters. It is from the estimation of a model like this that we adduce evidence about the foundational importance of R&D investments in the technology transfer process.

In Chapter 12 we explore scientific publications as a relevant technology, but frequently overlooked, transfer mechanism. Publications from federal laboratories and agencies are not a technology transfer mechanism that is generally discussed in the company of other more traditional mechanisms.

Three new (i.e., new to the technology transfer literature) technology transfer metrics are discussed and quantified in Chapter 13. Licensing success rates, filing ratios, and transfer rates have only very recently been added in the relevant literature dialogue.

In Chapter 14, we depart slightly from the primary focus of this book, and we pointed out above and again here that new technologies do not exclusively result from federally funded R&D allocated to and used in federal laboratories and agencies. Our discussion in this chapter thus departs from our strict interpretation of public sector innovation in the previous chapters to a discussion of innovation that is supported by the public sector. In the United States, and in most industrialized nations, private sector firms are also a source of new technologies that become innovations. Our discussion of technology transfer of public sector innovation would not be complete if we did not discuss the transfer of private sector technologies and innovations that resulted from federally funded R&D. Our emphasis is on technology transfers from firms that received Small Business Innovation Research (SBIR) awards.

Finally, Chapter 15 concludes this book with policy remarks and recommendations for ways through which the federal laboratories and agencies might embrace academic and policy research toward the goal of establishing best practices in public sector technology transfer.

NOTES

1. As discussed below, the Technology Partnerships Office within the National Institute of Standards and Technology, through its annual summary publications, has made public detailed metrics on many technology transfer mechanisms. However, from our vantage point, many researchers are unaware of the availability of these metrics, and that is one reason that we report in the appendix to Chapter 7 all such compiled data.
2. See https://www.nist.gov/fy-2019-presidential-budget-request-summary/technology-transfer.
3. The phrase *national laboratories* refers to mission-driven research centers, and they are generally federally funded research and development centers (FFRDCs) or government owned, contractor operated (GOCO) laboratories.
4. There are different estimates of the number of federal laboratories in the United States. One lower-bound estimate comes from the FLC, which counts as its members more than 300 federal laboratories (FLC, 2017).
5. See https://www.etymonline.com/word/innovate.
6. See https://www.etymonline.com/word/innovation.
7. For a valuable discussion of the evolution of the concept of public sector innovation, see, for example, León, Simmonds, and Roman (2012). For a review of the academic literature on public sector innovation, see, for example, De Vries, Bekkers, and Tummers (2016).
8. Our definitions have evolved over time, and they have been influenced by Nightingale (1998). See Leyden and Link (2015) for an extended discussion of these terms.
9. Our focus on technology that is transferred from federal laboratories and agencies is

indeed motivated by the availability of the data that we analyze in subsequent chapters as well as by the conspicuous void of empirical analyses on the subject—a void that we hope that we are beginning to fill.

10. See Link and Scherer (2005).
11. Regarding the productivity slowdown, see also Link and Link (2009), Link and Scott (2013), Bozeman and Link (2014), Leyden and Link (2015), and Link and Scott (2017).