Assessing the economic value relationship between academia and industry

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ABSTRACT

Introduction: Previous literature indicates that standard economic analysis is often not well suited for the evaluation of research investments, necessitating the use of other methods. This work uses a mixed methods approach to investigate the economic value relationship between academia and industry, towards a holistic understanding of how research benefits arise and can be measured to provide greater insight into the drivers of the system, its sustainability, and economic competitiveness.

Methods: Each of the pillars of the National Innovation System (NIS) model, adapted to assess the economic value relationship between academia and industry, were evaluated. The first research element (government) focused on the macroeconomic and regulatory context by evaluating the federal SBIR/STTR programs through an in-depth case study. The second element focused on the education and training system (academia) by assessing how technology transfer offices at universities measure research value. The final element of the study (industry) focused on communication infrastructures by investigating the digital tools used by medical technology firms to accelerate innovation beyond organizational boundaries. The academia and industry research elements each consisted of document review and semi-structured interviews.

Results: While the federal SBIR/STTR programs were found to be a significant catalyst for the academic-industry economic value relationship, especially at the most crucial proof-of-concept stage, policy discrepancies between stakeholders might affect the desired program outcomes. Consensus measures and metrics were identified for both academia and industry, which inform the product and factor market conditions that drive academic-industry innovation capacity. In many cases, challenges behind these measures were also raised, highlighting the need for sensitivity to institutional mission, culture and other conditions when applying these measures. Valuation differences were also found to exist between public and private universities in entrepreneurial engagement and economic development.

Conclusions: The measurement categories across both academia and industry describe adequate, dependable resources as the overarching product market theme and a talented and interconnected workforce as the overarching factor market theme. Taken together, they lead to more effective knowledge generation and diffusion, as well as a more informed NIS model with specific and practical utility for the economic value relationship between academia and industry.
ACKNOWLEDGEMENTS

There are a number of organizations and people without whom this work would not have been possible, and to whom I would like to express my gratitude.

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# TABLE OF CONTENTS

ABSTRACT ...........................................................................................................................................II

ACKNOWLEDGEMENTS ...................................................................................................................III

TABLE OF CONTENTS ...................................................................................................................IV

LIST OF ABBREVIATIONS ..............................................................................................................VII

LIST OF TABLES ............................................................................................................................IX

LIST OF FIGURES ..........................................................................................................................IX

I. BACKGROUND AND SIGNIFICANCE ..............................................................................................10

A. RATIONALE FOR THIS STUDY .....................................................................................................10

B. CONTEXT FOR RESEARCH VALUE ASSESSMENT ....................................................................11
   i. Negative or indirect impact ...........................................................................................................11
   ii. External influences ......................................................................................................................12
   iii. Research is cumulative .............................................................................................................13
   iv. Risk - reward .............................................................................................................................13
   v. Value perspective .......................................................................................................................14
   vi. Alternative strategies ................................................................................................................14
   vii. Distortions resulting from measurement .................................................................................15
   viii. Conclusion .............................................................................................................................16

C. THE AMERICAN RESEARCH SYSTEM .........................................................................................16
   i. Complementary roles of industry, government, and philanthropy .............................................16
   ii. The role of philanthropy in research funding ............................................................................18
   iii. Research funding trends ..........................................................................................................19
   iv. Performers of scientific research ............................................................................................22

II. LITERATURE REVIEW ..................................................................................................................25

A. ECONOMIC RESEARCH ASSESSMENT .....................................................................................25
   i. Input indicators ..........................................................................................................................25
   ii. Output and outcome indicators ...............................................................................................26
   iii. Conclusion ...............................................................................................................................28

B. MODELLING SCIENCE, TECHNOLOGY AND INNOVATION SYSTEMS ...........................................28
   i. Model perspectives ....................................................................................................................28
   ii. Innovation theory at the National level .....................................................................................29
   iii. Innovation theory at the Firm level ..........................................................................................32

iv
\textit{vi. Academic interview results} ................................................................. 109
\textit{iii. Industry interview results} ................................................................. 129
D. \textbf{TRIANGULATION THEMES} .............................................................. 136
   i. \textit{Consensus metrics} ............................................................................. 136
   ii. \textit{Innovation determinants} ................................................................. 137
   iii. \textit{Overarching measurement themes} ................................................... 139
   iv. \textit{Socio-political factors} ...................................................................... 141

\textbf{VI. DISCUSSION} .................................................................................. 144
A. \textbf{FINDINGS} ......................................................................................... 144
   i. \textit{Government} ....................................................................................... 144
   ii. \textit{Academia} ......................................................................................... 145
   iii. \textit{Industry} .......................................................................................... 149
   iv. \textit{Universal value drivers across academia and industry} ....................... 156
B. \textbf{FINDINGS IN RELATION TO HYPOTHESES} .................................. 157
C. \textbf{STRENGTHS} ...................................................................................... 159
D. \textbf{LIMITATIONS} .................................................................................... 160

\textbf{VII. CONCLUSIONS} ............................................................................ 165
A. \textbf{SYSTEM-LEVEL VALUE DRIVERS} .................................................... 165
   i. \textit{Proposed measurement framework} .................................................... 167
B. \textbf{IMPLICATIONS} ................................................................................ 169
C. \textbf{RECOMMENDATIONS} ...................................................................... 173
D. \textbf{FUTURE RESEARCH} ........................................................................ 174

\textbf{VI. REFERENCES} ................................................................................ 176

\textbf{APPENDICES} ..................................................................................... 185
A. \textit{DISCUSSION GUIDE FOR ACADEMIC RESEARCH ELEMENT} ............. 185
B. \textit{INTERVIEW REQUEST AND DISCUSSION GUIDE FOR INDUSTRY RESEARCH ELEMENT} ............. 186
C. \textit{ANNOTATED BIBLIOGRAPHY OF SELECTED STUDIES} ....................... 187
D. \textit{REFERENCE TECHNOLOGY TRANSFER MEASUREMENT SCHEME COMPARISON} ....................... 196
E. \textit{REFERENCE HEALTH INDUSTRY REPORT EVALUATION} ...................... 199
F. \textit{CODING THEMES} .............................................................................. 201
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ACA</td>
<td>Affordable Care Act</td>
</tr>
<tr>
<td>APLU</td>
<td>Association of Public and Land-grant Universities</td>
</tr>
<tr>
<td>AUTM</td>
<td>Association of University Technology Managers</td>
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<tr>
<td>BRDIS</td>
<td>Business R&amp;D and Innovation Survey</td>
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<tr>
<td>CC</td>
<td>Carbon Copy</td>
</tr>
<tr>
<td>CEO</td>
<td>Chief Executive Officer</td>
</tr>
<tr>
<td>CICEP</td>
<td>Commission on Innovation, Competitiveness, and Economic Prosperity</td>
</tr>
<tr>
<td>CRM</td>
<td>Customer Relationship Management</td>
</tr>
<tr>
<td>DHHS</td>
<td>Department of Health and Human Services</td>
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<tr>
<td>DALY</td>
<td>Disability-Adjusted Life Year</td>
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<tr>
<td>EHRs</td>
<td>Electronic Health Records</td>
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<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FY</td>
<td>Fiscal Year</td>
</tr>
<tr>
<td>GTO</td>
<td>Global Technology Outlook</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GERD</td>
<td>Gross Expenditures (domestic) on R&amp;D</td>
</tr>
<tr>
<td>HRI</td>
<td>Health Research Institute</td>
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<tr>
<td>HERD</td>
<td>Higher Education Research and Development Survey</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>IP</td>
<td>Intellectual Property</td>
</tr>
<tr>
<td>IQ</td>
<td>Intelligence Quotient</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NCSES</td>
<td>National Center for Science and Engineering Statistics</td>
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<tr>
<td>NIS</td>
<td>National Innovation System</td>
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<tr>
<td>NIST</td>
<td>National Institute for Standards and Technology</td>
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<tr>
<td>NIH</td>
<td>National Institutes of Health</td>
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<tr>
<td>NRC</td>
<td>National Research Council</td>
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<tr>
<td>DBASSE</td>
<td>National Research Council Division of Behavioral and Social Sciences and Education</td>
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<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Cooperation and Development</td>
</tr>
<tr>
<td>PWC</td>
<td>PriceWaterhouseCoopers</td>
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<tr>
<td>PPP</td>
<td>Purchasing Power Parity</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<tr>
<td>ROI</td>
<td>Return On Investment</td>
</tr>
<tr>
<td>S&amp;T</td>
<td>Science and Technology</td>
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<tr>
<td>STAR METRICS</td>
<td>Science and Technology for America’s Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness and Science</td>
</tr>
<tr>
<td>STI</td>
<td>Science, Technology and Innovation</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, Technology, Engineering, and Mathematics</td>
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<tr>
<td>SFI</td>
<td>Significant Financial Interest</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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<tr>
<td>SBIR</td>
<td>Small Business Innovation Research program</td>
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<td>STTR</td>
<td>Small Business Technology Transfer Research program</td>
</tr>
<tr>
<td>SaaS</td>
<td>Software as a Service</td>
</tr>
<tr>
<td>TFP</td>
<td>Total Factor Productivity</td>
</tr>
<tr>
<td>USDA</td>
<td>U.S. Department of Agriculture</td>
</tr>
<tr>
<td>DoD</td>
<td>U.S. Department of Defense</td>
</tr>
<tr>
<td>DoE</td>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>USPTO</td>
<td>United States Patent and Trademark Office</td>
</tr>
<tr>
<td>UNC</td>
<td>University of North Carolina</td>
</tr>
<tr>
<td>UPMC</td>
<td>University of Pittsburgh Medical Center</td>
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<tr>
<td>VC</td>
<td>Venture Capital</td>
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LIST OF TABLES

Table 1. International Comparisons of Gross Domestic Expenditures on R&D ................................................. 20
Table 2. Total U.S. Research Expenditures by Performing Sectors ................................................................. 24
Table 3. SBIR vs STTR Program Hallmarks .................................................................................................. 43
Table 4. Sample Frame for the Academic Research Part .................................................................................. 58

LIST OF FIGURES

Figure 1. Total Funding Share of U.S. Research ............................................................................................... 17
Figure 2. Basic and Applied R&D Allocations for Six Largest Federal Agencies ........................................ 21
Figure 3. Basic and Applied R&D Allocations for Six Largest Federal Agencies ........................................ 21
Figure 4. Annual Federal Spending by Fields of Research ........................................................................... 22
Figure 5. Performance Share of US Total Basic and Applied Research .................................................... 23
Figure 6. Performance Shares of Federally Funded U.S. Research ............................................................... 24
Figure 7. OECD National Innovation System Model .................................................................................... 31
Figure 8. First Generation “Technology-Push” Model .................................................................................. 32
Figure 9. Second Generation “Market Pull” Model ...................................................................................... 33
Figure 10. Third Generation “Coupling” Model .......................................................................................... 33
Figure 11. Fourth Generation “Integrated/Parallel” Model .......................................................................... 34
Figure 12. Fifth Generation “Network” Model ........................................................................................... 35
Figure 13. Sixth Generation “Open Innovation” Model ................................................................................ 36
Figure 14. Adapted National Innovation System Model ............................................................................. 46
Figure 15. Research Design Overview .......................................................................................................... 53
Figure 16. Influences of Processes, Outputs and Outcomes on Research Impact ........................................... 82
Figure 17. Compared Funding Allocations by the SBIR/STTR and VC ......................................................... 99
Figure 18. Common Innovation Goals between Drug and Device Companies ........................................... 101
Figure 19. Drug and Device Companies are Using Social Media for Innovation ........................................ 103
Figure 20. Digital Technologies of Highest Strategic Importance ............................................................. 104
Figure 21. Drug and Device Companies’ Use of Mobile Technology ........................................................... 106
Figure 22. National Innovation System - Academic-Industry Value Relationship ......................................... 169
I. BACKGROUND AND SIGNIFICANCE

a. Rationale for this Study

Since the establishment of the National Science Foundation and the start of the golden years of expansion of the National Institutes of Health nearly seven decades ago, science and technology have flourished in the United States. The U.S. currently spends more than any other nation on research and development, with some marked achievements. Notably, discoveries in nature and space have shaped many aspects of modern day life, and the benefits yielded by these discoveries have strengthened the position of the United States as a leader in global innovation. At present, the need for a strong and productive research environment is more essential than ever.

Government and industry are both significant stakeholders investing in the system of scientific research, each making complementary investments that have made societal benefit possible. In times of economic austerity, leading to both contracting government budgets and declining industry profits, measuring the economic and societal returns on research investments becomes especially important. One particular way this can be done is by identifying the variables that govern the economic returns from research to inform future investments that can advance new technologies to drive the American economy, increase quality of life, and create jobs.

Scientific research widely contributes to our lives and touches it in a multitude of ways. The central question of this work is if and how the value created by research can be measured, used in a meaningful way, and leveraged towards desirable economic outcomes. What are the returns on our research investment and can metrics and measures
be used to guide policies and strategies that can help insure global competitiveness in both academia and industry?

This work aims to contribute to the body of knowledge investigating the economic value relationship between academia and industry. A holistic understanding of how research benefits arise and can be measured can provide greater insight into the drivers of the system, its sustainability, and economic competitiveness derived from it. Specifically, it is important to understand how the discovery, dissemination, and application of knowledge derived from scientific research achieves innovation, and ultimately results in wide adoption and use.

b. Context for Research Value Assessment

The creation, transfer and ultimate value derived from the application of knowledge is difficult to measure owing to the complex relationship between the generation and dissemination of knowledge and the societal outcomes this produces. As such, assessing the impact of research - which drives its ultimate value to society - is inherently difficult and often creates even more challenges than evaluating the quality of such research, for a variety of reasons that are discussed in this section (adapted from Group of Eight, 2011).

i. Negative or indirect impact

While the focus of research is often on its positive results, it is important to balance the beneficial effects of research against its sometimes unintended or undesired negative effects. The potential negative health and environmental impact of chemicals
such as pesticides, plastics, and food additives provide one example. Research goals can also be directed at avoiding or minimizing harm and, as such, their results are a reduced negative impact rather than a direct positive one. Much public health disease prevention, environmental toxicology, and social science crime prevention research falls into this category. Furthermore, research can sometimes identify new problems and provide an opportunity to respond, but without necessarily inducing concrete outcomes. The resulting awareness of a problem neither has a directly positive or negative impact; global climate change research is one such example. Nevertheless, while the negative or indirect impact resulting from research can sometimes not be measured in immediate economic terms, it remains important to recognize the existence of these impacts and consider their broader effects on society.

**ii. External influences**

It is important to recognize that while research results are often achieved by scientists, their ultimate commercial applications are often realized by distinctly different commercial stakeholders and consumers. As such, scientists often have little control over how their discoveries are creatively applied in the marketplace and result in commercial innovations. It is also possible that, given the intellectual and investment capital as well as the many diverse skillsets required to realize the commercial potential of an invention, discoveries are never applied because the required complementary resources are lacking. One illustrative example would be the use of vaccines: regardless of a particular vaccine’s effectiveness, it is the willingness of the population to be vaccinated and the respective health authority’s ability to execute on a vaccination program that drives its impact. Furthermore, due to the many complementary and distributed resources required
to achieve value from research, it is possible for research impact to occur in completely different countries from where the research originally took place.

**iii. Research is cumulative**

All research builds on earlier research and, as such, breakthroughs in one scientific discipline often rely on advances in another to occur. One prominent example is the invention of the computer, which enabled advanced computation and analysis in a multitude of other fields that would not have been possible without the initial invention. Similarly, in the field of medicine the ability to accurately diagnose a disease and the availability of a cure are often very closely linked with one depending on the other to progress.

The collective body of knowledge generated by all combined science also provides the capacity to respond to unforeseen events. Discoveries that are currently unused can provide an “insurance policy” against future disasters, challenges, or even new opportunities that might arise. For example the Corning “Gorilla Glass” invention sat on the shelf for many years until the advent of the smartphone, which required exactly the material properties that Gorilla Glass possessed for use in portable touch screen displays.

**iv. Risk - reward**

Research is inherently high-risk and often fails. However, it is important to recognize that for research to advance knowledge, unintended or even negative results are still of value. It is thus also important to normalize value assessments based on these high failure rates in order to undertake a meaningful evaluation of research impact. As such, a
level of analysis beyond the individual project, considering the types of research activity, the institution as a whole, or even the entire funding program are often appropriate to assess research value.

v. **Value perspective**

Research sometimes has a significant social underpinning and value attribution that does not necessarily reflect its economic or other direct societal returns. Some of the intangible benefits this creates, such as social cohesion or building a national identity, should be considered. A prominent example is space exploration, including both the race to the moon in the 1960s and the ongoing quest for deep space exploration.

It is also important to note that the value attribution of research is often a matter of perspective. An auto plant assembly line worker who just lost her job to advances in robotic automation might view the value of advanced robotics completely different to the engineers who devised the technology. It is also possible that value attribution can change over time. For example, a fishing moratorium to preserve certain species might be viewed very negatively by fishermen, but over time might save an industry that would have died out without research inspired natural resource management. Another such example are childhood obesity reduction programs, which, while in the short run might impact the food industry, may have very significant population health benefits in the long run.

vi. **Alternative strategies**

Another hallmark of research is its competitive nature, with numerous, diverse teams across the globe often working on solving problems in many different and possibly similar ways. As such, it is inevitable for some pathways to fail, which can still provide
valuable insights into advancing alternate strategies, or enable multiple solutions to the same problem to emerge. In a complex world, having multiple options to solve a problem is often an advantage, but it is still important to consider the opportunity cost. Would investing in a different strategy or even research to solve a different problem have yielded greater benefit to society? This question becomes even more complicated when considering the counterfactual: would not investing in certain research but in another policy approach altogether yield a greater return? One such example is the balance between investing in military defense research versus investing in humanitarian and other forms of cooperative aid.

**vii. Distortions resulting from measurement**

The use of metrics aimed at evaluating research impact can influence behavior and have a distorting effect, especially when linked to funding allocation schemes. One example is the measurement of patenting for assessing research impact, which can lead to extensive patenting and costly intellectual property (IP) portfolios that might never be recouped through license returns, and may even hamper research advances by limiting the freedom to operate in certain areas of science where there is a thicket of patents.

Another way in which research metrics can distort behavior is the possible implication that areas of science that are heavily measured receive more visibility and attention than less measured areas, which may distort funding allocations. One possible example is research in applied computer science and (cybersecurity) applications versus the fundamental mathematics research into the underlying algorithms - the latter is often less prominently measured but often crucial for downstream applications.
viii. Conclusion

There are clear accountability and other reasons for measuring the impact of research and assessing its value. However, it is important to recognize that value assessments of research need to consider the uncertainties, ambiguities, and long timeframes unique to research, as well as the range of stakeholders involved in realizing the societal, commercial and other outcomes; combined, these factors will often call for interpretation beyond metrics.

c. The American Research System

As the largest R&D performer in the world (see section c.iii), the U.S. research system has developed rather freely, with a variety of networks, researchers and investors that can interact largely unconstrained. This section provides an overview of this research system, its main stakeholders, and the highlights of the research-innovation dynamic.

i. Complementary roles of industry, government, and philanthropy

According to the National Science Foundation, the industrial share in research funding has not changed significantly between 1953 and 2009 (Figure 1). The governmental share, however, has seen a significant period of decline since the early 1960s, congruent to the decline of investment in defense research funding. This is of particular note when considering proof-of-concept research, which is less likely to receive industry funding because it is often viewed as too risky, but is essential in bridging the gap between basic research and development and innovation (National Research Council 2005a, 2013c).
Industry investments in research are often aimed at leveraging internal funding, governmental contracts, and private contributions – often to a higher degree than publicly funded research. Given the fact that industries focus on selling products in many markets, research can be funded globally but is more likely to be conducted in the United States than development (National Science Foundation, 2012). This is important in considering the framework of industry-based research, as it can attract foreign investments alongside federal funding.

Government typically funds research with a long time horizon, a process
increasingly called upon to fund proof-of-concept research, which reduces investment risk for the private sector and encourages follow-on industry R&D investments. While the types of research funded by the government are inherently high risk and will not always meet their objectives, there can still be an attributed value even for dead ends in research. Indirect value can come from talent acquisition, changing the course of a research objective, and even unintended discoveries that were never perceived or planned at the outset. It is important to note that this type of funding is intended for transitioning research into development by funding the gaps not supported by industry and other funding sources. Another major area of public research investments is in infratechnology, which generates quasi-public goods that can provide a framework for industrial development. The National Institute of Standards and Technology, U.S. Department of Defense (DoD), and U.S. Department of Energy (DoE) engage heavily in these types of funding.

It is fair to surmise that, in general, the government tends to invest at the front end of the research spectrum, while industry invests primarily in its end products. This is because government is primarily focused on growing the foundation of shared knowledge for the future to ensure a continued supply of new innovations and societal benefit, while industry invests more heavily in the development of products and services that can more directly be converted into profit.

**ii. The role of philanthropy in research funding**

While industry and government provide the dominant share of research funding, the amount philanthropy contributes is rising rapidly. Whereas in 1953 the contribution to research made by nonprofit sources was only 3%, by 2011 it reached 8% (see Figure 1),
with this trend expected to continue. Totaling approximately $4 billion a year, foundations and individuals are significant contributors to research at U.S. universities and colleges, where these contributions can amount to as much as 30% of their annual research expenditures (Murray, 2012). The most striking way in which philanthropic research investments differ from those of the government is that funding priorities are often strongly shaped by the interests of the donors, often in favor of translational medical research for specific diseases rather than fundamental science. According to Murray (2012, p. 1 ibid.):

“The documented extent of science philanthropy and its strong emphasis on translational medical research raises important questions for federal policy makers. In determining their own funding strategies, they must no longer assume that their funding is the only source in shaping some fields of research while recognizing that philanthropy may ignore other important fields.”

iii. Research funding trends

With $429 billion in total R&D spending in 2011, the U.S. is currently the largest R&D performer in the world, accounting for roughly a third of total R&D expenditures worldwide. Table 1 provides an international comparison of gross domestic R&D expenditures and R&D share of gross domestic product for the top twenty nations and the EU, for the most recent year available.
Table 1. **International comparisons of gross domestic expenditures on R&D**

<table>
<thead>
<tr>
<th>Region/country/economy</th>
<th>GERD (PPP $millions)</th>
<th>GERD/GDP (%)</th>
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<tbody>
<tr>
<td>United States (2011)a</td>
<td>429,143.0</td>
<td>2.85</td>
</tr>
<tr>
<td>EU (2011)</td>
<td>320,455.9</td>
<td>1.94</td>
</tr>
<tr>
<td>China (2011)</td>
<td>208,171.8</td>
<td>1.84</td>
</tr>
<tr>
<td>Japan (2011)</td>
<td>146,537.3</td>
<td>3.39</td>
</tr>
<tr>
<td>Germany (2011)</td>
<td>93,055.5</td>
<td>2.88</td>
</tr>
<tr>
<td>South Korea (2011)</td>
<td>59,890.0</td>
<td>4.03</td>
</tr>
<tr>
<td>France (2011)</td>
<td>51,891.0</td>
<td>2.24</td>
</tr>
<tr>
<td>United Kingdom (2011)</td>
<td>39,627.1</td>
<td>1.77</td>
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<td>Russian Federation (2011)</td>
<td>35,045.1</td>
<td>1.09</td>
</tr>
<tr>
<td>Taiwan (2011)</td>
<td>26,493.1</td>
<td>3.02</td>
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<td>Brazil (2010)</td>
<td>25,340.2</td>
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<td>Italy (2011)</td>
<td>24,812.1</td>
<td>1.25</td>
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<tr>
<td>India (2007)</td>
<td>24,305.9</td>
<td>0.76</td>
</tr>
<tr>
<td>Canada (2011)</td>
<td>24,289.3</td>
<td>1.74</td>
</tr>
<tr>
<td>Australia (2010)</td>
<td>20,578.1</td>
<td>2.20</td>
</tr>
<tr>
<td>Spain (2011)</td>
<td>19,763.1</td>
<td>1.33</td>
</tr>
<tr>
<td>Netherlands (2011)</td>
<td>14,581.5</td>
<td>2.04</td>
</tr>
<tr>
<td>Sweden (2011)</td>
<td>13,216.2</td>
<td>3.37</td>
</tr>
<tr>
<td>Turkey (2011)</td>
<td>10,826.9</td>
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<tr>
<td>Switzerland (2008)</td>
<td>10,525.2</td>
<td>2.87</td>
</tr>
<tr>
<td>Israel (2011)</td>
<td>9,822.7</td>
<td>4.38</td>
</tr>
</tbody>
</table>

**NOTES:** EU = European Union; GDP = gross domestic product; GERD = gross expenditures (domestic) on R&D; PPP = purchasing power parity. Figures for the United States in this table may differ slightly from those cited earlier in the chapter. Data here reflect international standards for calculating GERD, which vary slightly from the National Science Foundation’s protocol for tallying U.S. total R&D. The table includes a ranking of the top 20 nations and the EU based on most recent annual GERD available. Year of data is listed in parentheses. Foreign currencies are converted to dollars through PPPs. Data for Israel are for civilian R&D only. SOURCE: Data from National Science Foundation (2014a).

As noted earlier in Figure 1, the federal government is the largest research contributor, with funding programs spread across 20 agencies that fund their own programs according to their missions and priorities. Figure 2 and 3 show the distribution of basic research, applied research, and development among the R&D budgets of the leading six federal R&D funding agencies.
**Figure 2.** Basic and applied R&D allocations for six largest federal agencies


*SOURCE: Adapted from American Association for the Advancement of Science (2013b).*

---

**Figure 3.** Basic and applied R&D allocations for six largest federal agencies

*NOTE: Agency abbreviations – see legend under Fig.2.*

*SOURCE: Adapted from American Association for the Advancement of Science (2013b).*
Figure 4 breaks down funding trends according to the field of research. It depicts how funding by the federal government has increased 20% for life sciences, making up more than 50% of government funding in basic and applied research since 1980. It also shows that with the exception of the brief funding episode under the American Recovery and Reinvestment Act, federal support for research in the fields of physics, chemical engineering, geological sciences, and electrical and mechanical engineering have decreased by nearly one fifth. Computer science differs from these trends, with its share in funding from the federal government rising by over 60 percent (Merrill, 2013).

![Figure 4. Annual federal spending by fields of research](image)

*NOTE: Measured in billion USD dollars according to FY 2012. “Other” includes basic and applied research except R&D facilities.

iv. Performers of scientific research

There are several performers on the receiving end of federal research funding, namely federal labs, academic institutions, nonprofit organizations and institutes, hospitals, and government contractors. Federal labs have a dual role in generating mission-driven as well as commercial outputs. Universities and other academic
institutions contribute to the knowledge pool while generating a well versed work force capable of transitioning from academia to industry to create commercial potential from their attained skills and knowledge. Finally, contractors typically produce commercial products.

Looking at national research trends by the type of performer and the amount invested in research, it is industry that performs most of the U.S. research. This is reflected by the distribution of federal support by research performers in figure 5. Traditionally, universities have conducted most federally funded research; however, when differentiating between basic research and applied research, it becomes clear that industry leads in applied research (see Table 2). The share of industry in applied research has decreased over the past ten years. Additionally, the federal government’s share of research, whether conducted via contractors or within its own agencies, has significantly dropped over the last four decades.

![Figure 5. Performance share of US total basic and applied research](chart.png)

**Figure 5. Performance share of US total basic and applied research**

*SOURCE: Data from National Science Foundation (2014b).*
Figure 6. Performance shares of federally funded U.S. research.

NOTE: Differences in measuring character of work estimation, due to revisions in 1998 of business R&D, in 2008 for business R&D, and in 2010 for academic R&D, make the comparison between certain time periods inconsistent. Federal shares consist of funding allocated to both research and facilities for developing research. The sum of shares does not equal 1 since academic funding and state funding is not included.

SOURCE: Data from National Science Foundation (2014c).

<table>
<thead>
<tr>
<th>Table 2. Total U.S. Research Expenditures by Performing Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of work and sector</td>
</tr>
<tr>
<td>Basic Research</td>
</tr>
<tr>
<td>Private industry</td>
</tr>
<tr>
<td>Federal intramural</td>
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<tr>
<td>FFRDCs</td>
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<tr>
<td>Universities and colleges</td>
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<tr>
<td>Other nonprofit organizations</td>
</tr>
<tr>
<td>Applied Research</td>
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<tr>
<td>Private industry</td>
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<td>FFRDCs</td>
</tr>
<tr>
<td>Universities and colleges</td>
</tr>
<tr>
<td>Other nonprofit organizations</td>
</tr>
</tbody>
</table>

NOTE: FFRDC = federally funded research and development center. “Other” includes research not elsewhere classified. The federal shares include amounts for FFRDCs. SOURCE: Data from National Science Foundation (2014c). The federal shares include amounts for federally funded research and development centers.
II. LITERATURE REVIEW

a. Economic Research Assessment

This chapter reviews the most commonly used economic value assessment methods for research from both the input and output/outcomes perspectives, as well as their advantages and limitations.

i. Input indicators

The most prevalent input indicator to track the national science investment is the R&D spending to GDP ratio (often measured as gross expenditures on (domestic) R&D, also known as GERD). It is frequently used by organizations such as the OECD (OECD, 2015), United Nations (UNESCO, 2015), World Bank (World Bank, 2015), and the National Science Foundation (NSF, 2014a). It is a crude measure correlating R&D investment with innovative performance, most often used for cross-nation comparisons.

An overview of the R&D/GDP ratio for the 20 largest research performing nations and the EU is included in Table 1 under background section c.iii. As reported by the National Science Foundation, using OECD data (NSF, 2014a), the United States currently ranks eighth among the 20 largest R&D performers, with a GERD/GDP ratio of 2.85%. The main shortcoming of this indicator is that it conceals a great deal of cross-national heterogeneity. For example, Israel ranks highest for GERD/GDP at 4.38%, but no data is available on the allocation of civilian versus military R&D spending. For the U.S., it is known that a significantly larger portion of R&D spending is devoted to defense for the development and testing of military equipment than it is in most other high ranking nations. One area where R&D/GDP ratios can be particularly useful is in assessing the
momentum of other nations to evaluate where the strongest future competition might come from. Chinese R&D growth, for example, has outpaced all other nations with an annual increase in GERD/GDP of 20.7% over the past 10 years, compared to a competitive but much smaller 4.4% growth pace in the U.S. over the same 2001–11 period (NSF, 2014a).

Another common input indicator used for individual industries and sectors is a similar ratio of R&D divided by net sales, known as “R&D intensity”. R&D Intensity in the U.S. is tracked through the Business R&D and Innovation Survey (BRDIS), which was developed and is co-sponsored by the National Science Foundation and the U.S. Census Bureau (NSF, 2015). Even though it measures industry R&D, the ability of private enterprises to successfully conduct this work depends on the availability of various factors, such as a strong science base and robust federal funding for basic and proof-of-concept research. The prevailing rationale stipulates that the more effectively government supplies research inputs, the higher the industry return on prospective R&D investments, and the higher the associated R&D intensities (NRC, 2014).

ii. Output and outcome indicators

There are no direct R&D output metrics that can readily be tracked from the macro-economic perspective because, in economic terms, the output from research is considered an intermediate good, a stock of knowledge which can subsequently be built on for innovation purposes, but for which no direct markets exist that can be quantified (Guthrie et al., 2013). This significantly complicates assessing the value of research and has led to the use of outcome rather than output indicators.

A common research outcome indicator is return on investment (ROI). This has
been widely used for evaluating medical research (Passell, 2000), information technology (Dehning and Richardson, 2002), manufacturing technologies and other elements of the R&D system (Hall, 1996 and NIST, 2014). Two main approaches exist to undertake ROI calculations for research, but both present methodological challenges. The first method relates current output (using sales or net revenue) to conventional economic inputs such as labor, capital, purchased materials and services, and also includes a measure of the stock of knowledge available to the company being assessed. Another method relates the stock market value of the financial claims on a firm’s assets to the underlying asset, as well as a measure of the knowledge stock. While the latter is more forward looking by relying on the efficiency of financial markets in evaluating future firm prospects to consider future expectations, it can only be used for publicly traded firms and not for federal R&D investments (National Research Council, 2014).

Both methods rely on constructed measures of the knowledge stock available to the firm, which is challenging. The earliest literature on this topic used research intensity (R&D to sales ratio) and directly related it to total factor productivity (TFP, the growth in output adjusted for input change), as a measure of knowledge stock (Mansfield, 1965 and Griliches, 1980). This only works if R&D does not depreciate and its impact on output is immediate. Later work by Griliches addressed this by arbitrarily using a depreciation rate of 15%, similar to that of ordinary capital (Griliches, 1992, 1994). More recent work suggests that if the market value of private firms is used, the depreciation rate might be greater than 15% but will depend on the specific sector and point in time (Hall, 2005). The most recent school of thought has started incorporating measures for the spillover stock of R&D, as well as the social rates of return that are achieved from knowledge that
may still be useful after an individual firm can no longer extract direct monetary value from it (Hall et al., 2010).

Across the literature, the fact remains that many measurement issues must be addressed and that, ultimately, there is one central problem: the rate of return on R&D investments is not a constant and will vary over time. Outcomes from R&D are highly uncertain and revenue from sales depend on a large number of factors outside of the realm of the actual research. This makes ROI outcome indicators informative but certainly not a guide for future success based on the past performance it measures.

**iii. Conclusion**

The current scientific consensus is that standard economic analysis is often not well suited for the evaluation of research investments, and that other methods are needed. Various qualitative methods such as case studies, site visits/interviews, and some quantitative methods such as logic model driven economic analysis or data mining and visualization, may be more suited, particularly when used in combination with one another (Guthrie et al., 2013 and Lichtenberg, 2013).

**b. Modelling Science, Technology and Innovation Systems**

**i. Model perspectives**

Governmental value assessments of research most commonly employ Science, Technology and Innovation system (STI) models at the national level because this is typically the framework in which federal funding programs and education systems operate. Industrial STI models are most commonly assessed at the firm level because this
is the unit of most interest to industrial stakeholders. In assessing the economic value relationship between academia and industry, it is arguably important to consider innovation frameworks at both the national and firm level.

\textit{ii. Innovation theory at the National level}

Systems of innovation – especially at the national level - have been a topic of research interest for a long time. The first seminal work dates back to Friedrich List, who in 1885 published The National System of Political Economy (List, 1885). This publication predates the term “innovation”, but uses the term “political economy” in an almost identical fashion. It is believed to have provided the foundation for the German implementation of one of the best technical education and training systems in the world. List advocated new measures to promote and accelerate industrialization and economic growth by protecting emerging domestic industries, learning about new technologies and applying them.

The national innovation system concept has been attributed to the collaboration between Christopher Freeman and Bengt-Ake Lundvall in the 1980s (Freeman 1987 and Lundvall, 1992). Using the premise of List’s work, the concept of “political economy” from his early writings pointed Freeman towards the study of the development of economic superpowers (especially Japan), while Lundvall focused on the role of social interaction as a motivator for innovation. Innovation systems perform according to the types of interactions occurring between stakeholders and the quality of the communication taking place. As such, the national context in which these interactions take place is particularly important. According to Lundvall, innovation is a ubiquitous phenomenon in the modern economy. “In practically all parts of the economy, and at all
times, we expect to find ongoing processes of learning, searching and exploring, which result in new products, new techniques, new forms of organization and new markets” (Lundvall, 2000). Accordingly, innovation is not a step in a system, but something continuously happening. As a result, it is not a static process “but involves continuous interactivity between suppliers, clients, universities, productivity centers, standard setting bodies, banks and other critical social and economic actors” (Mytelka, 2001). For this reason, innovation impacts the national level more so than the individual, since beyond the individual act of learning by the firm or entrepreneur, a variety of systems can draw upon one another and influence the innovation process. This dynamic and social construct, according to Lundvall, dominates not only the system, but its institutional participants as well. After all, “an institutional context” is “constituted by laws, social rules, cultural norms, routines, habits, technical standards, etc.” (Lundvall, 2000). Its dynamic nature is attributed to “financial flows between government and private organizations, human flows between universities, firms, and government laboratories, regulation flows emanating from government agencies towards innovation organizations, and knowledge flows (spillovers) among these institutions” (Niosi, 2002).

While no universally adopted definition exists for the national innovation system, most of the working definitions are rooted in the OECD’s publications on national innovation system management, which has been a central topic in eight of its reports over the last 15 years (OECD, 1995, 1997, 1999, 2001a,b,c, 2002c, 2005). The NIS model, as defined by the OECD, describes a core set of organizational stakeholders and their relationships as: “the set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies, and which provides the framework
within which governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technology” (OECD, 1999).

Figure 7, adapted from the 1999 OECD report on managing national systems of innovation, provides the National Innovation System STI model, driven by knowledge generation, diffusion and exploitation; and primarily influenced by organizational capabilities and inter-relations. Contextual factors influencing these key drivers include the commercial, technological and regulatory environment in which firms operate. One key determinant of economic performance is national innovative capacity, which is an outcome of the complex network of inter-relations embedded in the NIS model.

**Figure 7. OECD National Innovation System model**

*Note: Actors and linkages in the innovation system. SOURCE: adapted from (OECD, 1999).*
iii. Innovation theory at the Firm level

Innovation theory at the firm level has been evolving since the 1950s, with a documented evolution across six significant shifts or generations. These models are not exclusionary but, rather, an evolution driven by forces such as the growing complexity and pace of industrial technological change, as well as other market changes necessitating model accommodation for ever-increasing external actors and internal and external processes (Rothwell, 1994; Chesbrough, 2006; Kotesmir and Meissner, 2013).

In the wake of the second world war, the first generation of firm-level innovation models in the 1950s and 60s (Figure 8) generally viewed the industrial innovation process as a linear progression, in which scientific discovery “pushed” technological development within firms and, ultimately, to the marketplace as new products. It assumed a linear relationship between R&D input and commercial product output without much consideration of the transformation process itself or the role of the marketplace (Carter and Williams, 1957).

![Figure 8. First generation “technology-push” model](SOURCE: Adapted from (Rothwell, 1994)).

The second generation of firm-level innovation models of the late 1960s and early 70s (Figure 9) took note of the strategic emphasis on marketing within firms and its influence on demand patterns. This led to increased consideration of market driven demand-side factors or “market-pull” in the innovation process, resulting in a new linear model where the market served as the source of ideas for directing R&D, which became a reactive component in the process (Clark, 1979 and Mensch et al., 1980). The main risk
in this model was its tendency to promote incremental technology-change rather than radical advances driven by long-term R&D programs (Hayes and Abernathy, 1980).

![Second generation “market pull” model](source)

**Figure 9. Second generation “market pull” model**

*SOURCE: Adapted from (Rothwell, 1994).*

The third generation of firm-level innovation models of the early 1970s to mid-1980s recognized how innovation is influenced by both increased technical capabilities driven by scientific advances as well as market needs. This led to an interactive or “coupling” model of innovation (Figure 10), characterized by interaction and feedback loops between science and technology and the marketplace (Mowery and Rosenberg, 1978). This model, however, could not adequately explain how the time to innovation could differ widely within the same sector (Rothwell et al., 1974).

![Third generation “coupling” model](source)

**Figure 10. Third generation “coupling” model**

*SOURCE: Adapted from (Rothwell, 1994).*
Two features that made the Japanese product development system so effective - integration and parallel development - hallmarked the fourth generation, firm-level innovation model advances of the early 1980s to the early 1990s. These “integrated” or “parallel” models (Figure 11) account for differences in intra-sector innovation speed due to the integration of suppliers earlier in the innovation process, as well as multiple departments within the firm working on projects simultaneously (in parallel) rather than sequentially (in series) (Imai et al., 1985).

Figure 11. Fourth generation “integrated/parallel” model

SOURCE: Adapted from (Rothwell, 1995).

The fifth generation firm-level innovation model that emerged between the mid-1990s and the early 2000s emphasizes the important role of stakeholders external to the firm, such as suppliers, customers, universities, government agencies, and partnerships/relationships with other firms (even competitors); it also highlights the importance of their interactive relationships in shaping an innovation environment (Figure 12). The fifth generation “network” model introduces the concept of systems
Thinking – how the firm’s internal innovation system interfaces with the national innovation environment (du Preez and Louw, 2008). Fifth generation models are also characterized by the introduction of informatics tools and systems, aimed at accelerating innovation processes and communications across the networking systems in terms of raising both development efficiency and speed-to-market through strategic alliances (Power and Dooly, 2014).

Figure 12. Fifth generation “network” model

SOURCE: Adapted from (Trott, 2005).

The latest sixth generation evolution in the firm-level innovation model that has emerged since the mid-2000s has expanded the incorporation of external stakeholders in both idea generation and path-to-market pathways. This model recognizes new development paradigms such as firms licensing out products for commercialization, as well as in-sourcing products developed by other firms as part of the innovation system. This latest “open innovation” model (Figure 13) recognizes how discoveries made
outside of the internal R&D unit can be leveraged in marketing new products (inbound open innovation), and how distribution pathways beyond the firm’s boundaries can be leveraged to market internally developed products (outbound open innovation) (Chesbrough, 2006).

Figure 13. Sixth generation “open innovation” model

SOURCE: Adapted from (Chesbrough, 2006).

iv. Conclusion

Common themes are often shared between the many science, technology, and innovation (STI) models at both the national and firm level; common inputs range from the knowledge basis, funding, capacity and training, and government policies. Outputs typically include new knowledge, new ideas, new strategies, and the documentation of these through publications or patents, outputs (new ideas, new techniques, and new instruments as revealed by publications, patents, or as a material good), and ultimately outcomes (including social wellbeing via spillovers to health, environmental, security,
and other indicators of economic and social progress).

While most comprehensive in defining the institutional elements that effect the functioning of the system - including activities at government, nonprofit, and for-profit research laboratories – the NIS model is not particularly well suited for stakeholders outside of government as it only considers national innovation capacity in its aggregate for the entire system. The model also does not account for management theory derived innovation catalysts that have been identified through six generations of firm-level innovation models.

This disconnect between innovation theory at the national and the firm level creates an opportunity to construct a more informed model for assessing the economic value relationship between academia and industry, which could be more widely utilized by academic and industry stakeholders beyond the realm of government alone.

c. The relationship between university research and industrial innovation

There is a dual flow of ideas and people associated with the research engagement between universities and industry. This has resulted in substantial patenting and licensing of university inventions, promoted by high levels of the inter-institutional mobility of researchers and new venture financing in the U.S. Industry-university collaboration. These have, in turn, been fueled by an interconnected network of channels ranging from the trained students, faculty consulting, publication of research advances, and industry-sponsored research.

As the U.S. research system has evolved, especially under the influence of significant growth in federal support for life science research conducted by universities,
university-directed management of patenting and licensing has grown alongside it. In particular, the Bayh-Dole Act, which was passed by congress in 1982 and provided universities with a broad mandate to manage and monetize their intellectual property, was a strong catalyst for universities’ commercial engagement. The topic of researcher productivity influenced by commercial activities, such as the formation of new firms, patenting and licensing, has been studied and has not been found negatively to affect scholarly productivity (Ding and Choi, 2011). Nevertheless, there have been some criticisms of U.S. universities seeking commercial interests by controlling their intellectual property, especially by information technology firms. As a result, some universities have experimented with new management models for their intellectual property rights, which this section explores in greater detail.

University policies regarding ‘start-ups’ can vary widely between institutions and can strongly affect start-up activity. Some research universities have offered incentive or reward systems for start-ups, for example by sharing royalty revenues from inventions with their inventors or by considering patents and start-up activity in tenure consideration. Examples include the University of Maryland, which considers patents and commercialization as part of its tenure review (Blumenstyk, 2012), Massachusetts Institute of Technology (Ittelson and Nelsen, 2003) and Carnegie Mellon University (Simmons, 2013), who have adopted similar supportive policies. Technology transfer at universities can serve a variety of goals, which may ultimately conflict with one another and, for this reason, need to be carefully considered and clearly formulated. For example, transferring technologies with the mindset of promoting the adoption of as many new technologies as possible into the marketplace would take significantly different
considerations, approaches, and measurements into account than the goal of achieving maximal monetary gain (Ewing Marion Kauffman Foundation, 2012).

The Bayh-Dole act and other federal policies have never imposed metrics for evaluating the performance of universities in transferring technologies and supporting industrial innovation. Some trade organizations, such as the Association of University Technology Managers (AUTM), track a number of core metrics including the number of new patents, the amount of licensing revenue, and the number of licenses and spin-off companies\(^1\). New technology transfer metrics can be useful and informative if there is consensus between universities on how to measure them, when they are considered with each specific university in mind, and if they cover the entire spectrum of channels in which the university influences industrial innovation, ranging from the training and placement of students to faculty research publications, faculty- or student-founded firms, patents, and licenses.

d. Federal funding programs aimed at strengthening the economic value relationship between academia and industry

The Small Business Innovation Research (SBIR) program was initiated by the United States legislature under the Small Business Innovation Development Act of 1982 (Small Business Administration, 2015a). Small Business Technology Transfer (STTR), a related program that requires small business applicants to partner with universities or not-for-profit research institutions, was initiated in 1992 (Small Business Administration, 2015a).

\(^1\) See AUTM annual licensing activity surveys starting in 1991 and available at [https://www.autm.net/Surveys.htm](https://www.autm.net/Surveys.htm) [July, 2015]
Both programs promote a stable economy by investing in innovation. They fund high risk unproven ideas and help them to survive “the valley of death” to commercialization. SBIR/STTR grants provide early stage funding that venture capitalists would likely decline given their preference for proven technologies and later stage investments (Wessner, 2008). The programs have proven themselves a saving grace for small business in need of proof-of-concept capital.

Currently, 11 federal agencies reserve 2.5% of their research and development budgets for SBIR grants. These include the Department of Agriculture, the National Institute of Standards and Technology at the Department of Commerce, the National Oceanic and Atmospheric Administration, the Department of Defense, the Department of Education, the Department of Energy, the Department of Health and Human Services, the Department of Homeland Security, the Department of Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Science Foundation. Of these, the five largest federal agencies, including the DoD, the DoE, the DHHS, NASA, and NSF reserve an additional 0.3% for STTR grants to small businesses partnering with universities or not-for-profit research institutions. Despite this smaller budget for STTR grants, the success rate is higher for phase I applications under this program (22.7% vs. 16.5% in FY20110) due to the fact that the STTR program has approximately 1/10th the number of applications than the SBIR program (Milman, 2012; SBA, 2015c).

Both SBIR and STTR programs have recently been extended through to 2017. Additionally, the percentage set aside for SBIR will gradually be raised over the extension period from 2.5% to 3.2%. The STTR set aside will be raised from 0.3% to
0.45%. The program changes will be instituted through a Small Business Administration (SBA) directive, finalized in December 2012.²

i. Eligibility

For the SBIR and STTR programs, the participating business entity must qualify as a small business at the time of award, in line with the following criteria: the company must be at least 51% American-owned as well be independently operated; the business must be for-profit with no more than 500 employees and be located in the U.S. (SBA, 2015d). From a practical perspective for academic researchers, a formal corporate entity needs to exist or be formed in order to submit an SBIR/STTR application through grants.gov. However, for NIH submissions, applicants do not need to meet the SBIR and STTR eligibility requirements until the time of award (SBIR, 2015d). As a result, it occurs fairly regularly that researchers only take up official responsibilities with the start-up and commence company operations at the time of award. An SBIR firm survey conducted by the National research Council showed that just over 20 percent of respondent companies were founded entirely or partly in lieu of a prospective SBIR award (Wessner, 2008).

ii. SBIR vs STTR

For the SBIR program, the Principal Investigator (PI), if there is a single PI, must be primarily employed by the company, devoting over 50% effort (dedicated available time) to the company or project at the time of award. The PI may have employment with

other entities (such as a university), but that effort cannot exceed 49% effort. Multiple PI grants are allowed under this program but, again, the small business must be the primary employer of the contact PI. While subcontracts are allowed under the SBIR program (Table 1), they cannot exceed 33% of the budget in Phase 1 and no more than 50% in phase II. In contrast, the STTR program requires a partner research institution that conducts a minimum of 30% of the budgeted work. Under this program, the small business entity must perform a minimum of 40% of the budgeted work. The remaining funds can be used by the company, the research partner, or for consultants or subcontracts. The STTR further differs by allowing the PI to be employed by either the small business or research partner. The contact PI must commit at least 10% research effort, whether their salary is budgeted or not. Thus, the SBIR may be more appropriate for a more established, small business that does not necessarily need an academic partner and allows more freedom in sub-contracting. In contrast, an STTR award may be more attractive to a new company that lacks a credible PI and/or needs access to academic labs/facilities.

Both of these programs fund commercialization in phases. Phase 1 grants fund limited feasibility studies that evaluate the viability and commercial potential of a technology. These grants are typically around $150,000; however, the median award at NIH for FY2011 was $208,000 for an SBIR and $227,000 for an STTR. Phase 2 grants fund more extensive prototype research and development, and are typically around $1 million. 100% of the research under these programs must be performed in the U.S. An overview of the hallmarks of both the SBIR and STTR programs is included in Table 3.
Table 3. SBIR vs STTR program hallmarks

<table>
<thead>
<tr>
<th></th>
<th>SBIR</th>
<th>STTR</th>
</tr>
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<tr>
<td><strong>Budget</strong></td>
<td>2.5% of total committed, Increase to 3.2% by 2017</td>
<td>0.3% of total committed, increase to 0.45% by 2017</td>
</tr>
<tr>
<td>NIH Budget (FY2011)</td>
<td>$578M</td>
<td>$74M</td>
</tr>
<tr>
<td>NIH success rate (FY2011)</td>
<td>16.5%</td>
<td>22.7%</td>
</tr>
<tr>
<td>Research institution required</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Contacts PI</td>
<td>&gt;50% employment by company</td>
<td>10% effort, can be employed by company or research partner</td>
</tr>
<tr>
<td>Multiple PIs allowed</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Subcontracts</td>
<td>Up to 33% in phase I</td>
<td>Required, 40% with business entity, 30% with research partner</td>
</tr>
</tbody>
</table>


### iii. Impact of the SBIR/STTR program

The SBIR and STTR programs constitute one of the largest public-private partnerships aimed at advancing technology innovation. The Congressional objectives of the program are to increase innovation, encourage participation by small companies in federal research and development (R&D), provide support for small firms owned by minorities and women, and resolve research questions for mission agencies in a cost-effective manner. A 2008 landmark report by the National Research Council concluded that the SBIR program is effective in meeting each of these objectives (Wessner, 2008). It was also shown that SBIR funded firms consistently account for a quarter of the R&D100 Award winners, providing “a powerful indication that the SBIR program has become a key force in the innovation economy of the United States” (Block, Keller, 2009). The R&D100 is a prestigious annual competition recognizing the 100 best inventions that have been incorporated into commercial products (R&D Magazine, 2015).
A number of well-known household products have been realized with SBIR or STTR support. In the early 1990s, a $50,000 phase I NIH SBIR grant followed by a $500,000 phase II grant to a small Snoqualmie, Washington start-up led to the development of the Sonicare toothbrush. The company, renamed Optiva, grew Sonicare to a $300 million brand before being acquired by Philips in 2000. iRobot, the company known for its Roomba and Scooba robotic vacuums, developed their line of household appliances based on the company’s Packbot technology, a robotic device developed with $9.2 million in DoD SBIR and STTR support to identify and dispose of explosives. iRobot is currently a NASDAQ-traded company with more than $465 million in revenue and over 600 employees. Another well-known success story is that of Qualcomm, the world’s leading provider of wireless technology and services, known for the wireless chips in most modern electronic devices. The company has a global workforce of over 17,500 and a market capitalization of more than $80 billion (SBA, 2015f). Dr. Irwin Jacobs, the founding company chairman and CEO emeritus has referred to the value SBIR program in his statement that: “with one of the grants, we developed some of the first chips we did at Qualcomm, if not the first. Making chips for cell phones is about two-thirds of our revenue today, and that was the base.” Qualcomm received $1.5 million in SBIR funding from the National Science Foundation and the Defense Department (Gaebler, 2011).

In the life sciences, leading global biotechnology companies such as Genzyme, Amgen, and Genentech all received SBIR funding at early stages of their company development (Audretsch et.al, 2011).
e. **Organizing framework**

The organizing framework for this study is the OECD’s NIS model, which provides a particularly strong and widely adopted reference framework for studying innovation systems. It clearly defines the essential organizational capabilities and institutional inter-relations needed for knowledge generation, diffusion and exploitation on a national level. However, since NIS-driven evaluation typically takes a systems perspective by measuring national innovative capacity occurring across the entire commercial, technological and regulatory environment in which firms and other stakeholders collectively operate, this framework is limited in its ability to measure specific value dimensions pertaining only to parts of the system - such as those associated with the economic value relationship between academia and industry. While much weaker in defining institutional inter-relationships outside of the firm environment, firm-level innovation models provide fertile ground for identifying innovation pathways, determinants and value dimensions, leading to a catalytic yield in economic outcomes based on management theory.

Accordingly, the NIS model in the current research thesis has been adapted for the academic/industry value relationship by focusing on product and factor market conditions specific to the academic-industry value relationship in order to arrive at academic-industry innovation capacity, considering the innovation determinants identified at the firm level (see Figure 14). While this work uses the NIS logic model pillars - including the education and training system, macroeconomic and regulatory context, and communication infrastructures - it also considers the specific firm-level innovation pathways identified through the six generations of management theory derived innovation
models at the firm level. Metrics and measures associated with economic value
generation between academia and industry are evaluated by incorporating the value
dimensions that are known to promote innovation pathways based on the most current
understanding of the innovation drivers at the firm level. Academic-industry specific
product and factor market conditions associated with the education and training system
(through university technology transfer), the communication infrastructure to enable firm
innovation (through the use of digital innovation accelerators in the medtech industry),
and the macroeconomic and regulatory context (through the federal SBIR and STTR
innovation research funding programs), will be assessed to arrive at a more informed
model to depict and assess the economic value relationship between academia and
industry, applicable to stakeholders in government, academia, and industry.

Figure 14. Adapted National Innovation System Model.
III. RESEARCH QUESTIONS AND HYPOTHESES

The common view of the economic value relationship between academia and industry is one in which “academia invents and industry invests” in commercialization. In reality, the value dynamic is much more intricate, with complex flows of intellectual, human and capital resources from universities to industry and vice versa, all occurring within a diffuse and interconnected system of innovation influenced by the macroeconomic and regulatory context. It is important to understand the nature of this interconnectedness, its motivators, inhibitors, and the nature of its growth, in order to better understand the value relationship between academia and industry, and then be able to measure it in the context of the entire national system of innovation.

As previously discussed, standard economic analysis is often not well suited to the evaluation of research investments, thus necessitating the use of other methods. Various qualitative methods such as case studies, site visits/interviews, and quantitative, logic model driven economic analysis might be more appropriate (Guthrie et al., 2013 and Lichtenberg, 2013).

The purpose of this research is to improve on the tools for assessing innovation systems by building on the existing assessment models through the identification and validation of consensus measures and metrics associated with each of the pillars of the academic-industry value model. The overarching aim is to arrive at a more actionable framework for the economic value relationship between academia and industry that takes into account innovation dynamics both at national and firm level. The following sections provide further detail of the research questions and hypotheses driving this research.
a. Research Questions

Using a modified NIS framework, it is possible to assign institutional proxies to each of the logic model pillars spanning academia, industry and government, and test their shared economic value relationship through the following questions:

1. How and why does the macroeconomic context of the federal SBIR and STTR programs influence the economic value relationship between academia and industry?

2. How and why do academic technology transfer officers measure the economic value relationship between the education and training system and industry?

3. How and why does (the medtech) industry use of communication infrastructure in the form of digital tools at the firm level affect the diffusion of knowledge and the presence of commercial innovations across institutional boundaries?

4. Can priority consensus themes be identified for the product and factor market conditions that drive the economic value relationship between academia and industry across the innovation system?

b. Literature Propositions

1. The SBIR and STTR federal funding programs constitute one of the largest public-private partnerships in the world aimed at advancing technology innovation. SBIR funded firms consistently account for a quarter of the R&D100 Award winners, providing “a powerful indication that the SBIR
program has become a key force in the innovation economy of the United States” (R&D Magazine, 2015). As several scholars have argued, and indeed as is the contention of the current thesis, a better understanding of the significance and influence of government on the economic value relationship between academia and industry within the national innovation system is needed in order to feasibly and accurately assess the returns on this investment (Block, Keller, 2009).

2. Although universities have adopted a variety of supportive policies to encourage innovation, higher returns on investment will rely on improved technology transfer measurements to assess the performance of university research (Blumenstyk, 2012; Ittelson and Nelsen, 2003; Simmons, 2013). As argued in much of the literature, universities will benefit from policies and evaluation tools that can increase the number of new technologies introduced to the marketplace (Ewing Marion Kauffman Foundation, 2012).

3. According to national research trends, industry performs the largest share of U.S. research. Innovation models have expanded their scope with increasingly complex internal and external network interfaces aimed at accelerating innovation processes through better communication systems (du Preez and Louw, 2008; Power and Dooly, 2014; Chesbrough, 2006). In order to gain new understanding of the economic value relationship between academia and industry, an assessment of current digital tools as communication system measures for innovation is, therefore, essential.
c. Research Hypotheses

**H1. GOVERNMENT** – The federal SBIR/STTR federal funding programs exert a significant influence on the economic value relationship between academia and industry, equal or greater than that of comparable private venture capital investments. In light of this, the distributed nature of the individual funding program across federal agencies, private industry and academic institutions may give rise to policy divergences that might affect the most efficient translation of knowledge into outcomes of value to society.

**H2. ACADEMIA** – if the economic value relationship between academia and industry is driven by overarching product and factor market conditions shared between them, this relationship can be elucidated by identifying consensus technology transfer metrics and measures as well as the systematic research valuation divergences across the diverse spectrum of American research universities.

**H3. INDUSTRY** – if the economic value relationship between academia and industry is driven by overarching product and factor market conditions shared between them, these can be elucidated by identifying the consensus measures for the communications infrastructures that enable innovation across organizational boundaries. Furthermore, within a specific industry (such as the medical technology industry), digital innovation accelerators are a significant driver for firm competitiveness that can be successfully identified and categorized for a more in-depth characterization of the diffusion of knowledge across innovation determinants.
IV. METHODS AND MATERIALS

a. Research Design

In addressing the research questions and hypotheses of this work, the central goal is to improve on the tools for assessing innovation systems by identifying consensus measures and metrics associated with each of the three pillars of the academic-industry value model, i.e. the modified NIS conceptual framework seen in Figure 15. Ultimately, the study aims to arrive at prioritized input, output and outcome metrics that take into account innovation dynamics both at the national and firm level, in order to assess the economic value relationship between academia and industry. This chapter details the methodology used to explore and assess this value relationship, and to reach the overall aim.

Grounding this study within the national innovation system, and in line with the three pillars, the research was divided into three elements, each with its corresponding methods. A mixed qualitative approach was followed in order to collect data appropriate for each of the three pillars of the NIS model, variously performing document review, conducting a case study, interviews with key stakeholders and a quantitative data assessment. Each of these are described in detail in the remainder of this chapter, but a summary is provided here:

The first element focuses on the macroeconomic and regulatory context by evaluating the federal SBIR/STTR program and the impact of its innovation oriented research investments, hereafter referred to as the government element of the research.
The method here consisted of a document review and descriptive analysis, followed by a single case study of a senior academic researcher who has had experience as both an academic and an industry participant in SBIR/STTR funded projects. The first stage of the case study evaluates the relative importance of the federal SBIR and STTR funding programs by comparing these with early stage venture capital investments. The second stage of the government research element conducts a case study of the program’s ability to advance research goals from both an academic and industrial perspective.

The second element focuses on the education and training system by assessing how technology transfer offices at universities assess the value of the research conducted within their universities, hereafter referred to as the academia element of the research. The method here consists of a document review and semi-structured telephone interviews with seven technology transfer officers.

The final element of the study focuses on the communications infrastructure by investigating the digital tools used by medical technology (medtech) firms to accelerate innovation in an open innovation environment, hereafter referred to as the industry research element. A qualitative research approach was followed for the academia and industry research parts, consisting of a document review and semi-structured interviews with key stakeholders. Figure 15 provides an overview of the overall research design.
Figure 15. Research design overview.

i. Research context

This study is the result of three different research assignments: one supporting the government research element of this work, the second the academic element, and the third the industry aspect. The following sub-sections detail each of these in turn.

Government

This study was conducted through an invited commentary by Nature Immunology on the topic of “the value of the federal SBIR/STTR in leveraging research programs”. This invitation was extended to Dr. Jay Kolls, professor of pediatrics and immunology and director of the Richard King Mellon Foundation Institute for Pediatric Research at
Children’s Hospital of Pittsburgh of the UPMC University of Pittsburgh School of Medicine. In addition to being a senior academic research investigator, Dr. Kolls also has STTR research funding experience. The researcher was invited by Dr. Kolls to collaborate on this commentary because of their prior working relationship on establishing a STTR funded start-up company based on Dr. Kolls research inventions in the area of mini-kexin, leading to the Minivax vaccine company.

This work investigates the utility of the federal SBIR/STTR programs in leveraging other federal research programs aimed primarily at academic research. It also investigates the alignment between the federal goals of the programs in promoting academic/industry collaborations, and university technology transfer and other policies in enabling this goal. To this end, the researcher completed a descriptive analysis comparing the federal SBIR/STTR investment to similar venture capital investments made by the private sector, followed by a detailed written case account by Dr. Kolls.

Academia

In reauthorizing the National Science Foundation (NSF), the America COMPETES Act - passed on January 4, 2011\(^3\) – also required the NSF to contract with the National Academies in order to assess and evaluate the measures and metrics used to determine the impact of research on society. The National Academies are the pre-eminent source of scientific information and advice that inform policy in the United States. The organization is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research.

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\(^3\) H.R. 5116, P.L. 111-358.
With NSF funding, the National Research Council (NRC) convened a committee of national experts to address the topic of research impact metrics. The committee convened four times throughout 2013 and had the benefit of expert input on specific topics, alongside holding a range of contemporary workshops, special sessions, and conferences on this topic during the study period. The resulting report, *Furthering America’s Research Enterprise*, was published in 2014. To support this report, the researcher completed a three-month Mirzayan Science and Technology Policy Fellowship hosted by the National Academies of Science, funded in-part by a Links with Industry and National Labs (LINK) grant from the Louisiana EPSCoR program. This assignment was followed by a one-year consulting appointment, supporting the Committee on assessing the value of research in advancing national goals. This was done by investigating the pathways through which research contributes to the US economy and well-being by assessing the quality of the research output of universities and other research institutions receiving federal government support, and the potential societal impact of research in advancing national goals. The researcher specifically contributed to this work by investigating how research creates value through the relationship between universities and industrial innovation, with specific emphasis on how the translation of research into commercial products and services might be increased. In collaboration with the National Academies study director Dr. Miron Straf, the report editor Dr. Ann Griswold, and Dr. Stephanie Shipp – NAS committee member assigned to oversee the technology transfer research element for the study and Deputy Director and Research Professor, Social and Decision Analytics Laboratory, with the Virginia Bioinformatics Institute at Virginia Tech; the researcher conducted a research assignment aimed at
investigating the metrics and measures used by university technology transfer offices to measure the value of their research.

**Industry**

This research was conducted by the researcher over a six month period as a visiting analyst with the PriceWaterhouseCoopers Health Research Institute (HRI), an industry thought-leadership group that provides new intelligence, perspectives and analysis on trends affecting all health related industries. The Institute focuses on actionable intelligence that can help executive decision makers, primarily in health-related industry sectors, thus it is largely a network of health industry leaders shaping the organization’s views. The HRI functions as an independent think-tank and is not sponsored by external businesses, government or other institutions.

In this particular study, the researcher studied digital industry vehicles for innovation across the medical technology industry spectrum to identify the optimum combination of technology and approaches that could nurture an innovative environment and, in turn, promote a measurable, value-driven health economy. This work was conducted under the supervision of Dr. Sarah Haflett, Senior Manager with PwC HRI. The results of this work were published in an August 2014 PwC HRI report, Digital Accelerators for a new Innovation Era. Specific contributions focused on the communications infrastructure that medtech companies use to enable, promote and assess both new product and service innovation in an open innovation environment beyond the boundaries of the individual firm.
b. Sample selection

Purposive sampling was undertaken in two stages for the academia and industry elements of the research respectively. The reason this sampling technique was selected is that it places the onus on sample criteria rather than the number of participants, seeking to elicit information-rich cases aligned with the research topic (Patton, 2005). Given that, as previously explained, research valuation through innovation metrics and measures is arguably best undertaken using an in-depth, qualitative approach, this technique thus seemed the most appropriate.

The sampling frame for both elements of the research was established using the following recruitment strategy:

i. Sample frame

Academia

The first stage of selecting academic stakeholders involved the selection of universities to be included in the study. Among those universities who participated in the 2014 Licensing Activity Survey (n=155) maintained by AUTM, only those that ranked among the top 50 for both total research expenditures and gross licensing income in 2013 were included in the sampling frame. This index and ranking were selected in order to ensure that participating cases would yield rich, nuanced information based on a well-established history of both ample research volume and consistent interaction with industry through licensing. This also served to exclude those universities that only have limited or no research expenditures and/or license revenues, as well as those for which no data was available for the 2014 reporting year. An overview of the sample frame considered for this study is provided in Table 4.
Table 4. Sample frame for the academic research part

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University system data encompassing multiple technology transfer offices were not counted toward the sample frame (denoted with *). These 4 institutions were replaced with universities with the highest average research and license revenue borderline rankings (denoted with ▲).

Source: 2014 Data from AUTM STATT Database.

To identify those universities that met the acceptance criteria, the Statistics Access for Technology Transfer (STATT) Database was used. STATT is an interactive online database maintained by AUTM, the national trade organization for technology transfer officers. STATT contains all the information obtained from the annual AUTM licensing Activity Surveys between 1991 and 2014. It contains data on licensing activity and income, startups, funding, staff size, legal fees, patent applications filed, royalties earned, research expenditures, as well as descriptive information on university structure, technology transfer staffing and other cost allocations.

A national committee of experts convened by the National Research Council to investigate “the value of research” judged the list of 38 universities and selected seven for in-depth semi-structured interviews (n=7). Considerations for inclusion included reasonable distribution across the considered spectrum of research expenditure/license revenue, as well as recognized thought leadership in the field of technology transfer (especially engagement in contemporary measurement frameworks such as STAR metrics). Additional considerations included the inclusion of both public and private institutions, and inclusion of institutions with and without an academic medical center. These key factors were considered as they have all been shown to be associated with significantly different research portfolios and, ultimately, commercial engagement.
patterns (Stagars, 2015).

The second stage was to identify the appropriate individual to interview at each of the selected universities. A list was compiled of the most senior officers associated with the technology transfer office or equivalent entity within each institution, most often with the title of executive director or CEO. The National Academies study director reviewed and approved the final list after consulting with the committee, which included seven technology transfer directors spanning both public and private research universities. Three of the interviewed technology transfer directors represented institutions that encompass an academic medical center. Two of the interviewees represented institutions among the top ten in total R&D expenditures among U.S. universities, collectively generating over $4.6 billion in research expenditures in 2014 according to STATT data.

The committee member assigned to oversee the technology transfer interviews invited each of the seven study participants from the identified universities through direct invitation for a telephone interview by electronic mail (Appendix A). For ease and efficiency of communication, these invitations were often sent alongside an endorsement from another committee member who had a personal relationship to the specific technology transfer executive, by copying them into the electronic invitation. The purpose of the study, as stated in the invitation, was “to investigate the pathways through which research contributes to our economy and well-being, and serves other national goals by investigating technology transfer metrics that universities collect and how they use them.” All seven interviews were conducted over the telephone within a timeframe of 60 minutes each, all within the span of 1 month in March of 2013. There were no non-responders. Further interview guide details are described under data collection below.
Industry

Sampling was also done in two stages to recruit participants for the industry aspect of the study. Firstly, relevant industry sectors and possible participants therein were identified. This was done by considering all health related industries in which the PriceWaterhouseCoopers Health Research Institute (PwC HRI) strategy consulting practice has a strong presence, in line with the core expertise of the institute where this research was conducted. Twelve senior practice leaders within PwC were consulted using 30 minute exploratory telephone interviews for guidance on the working hypothesis. This included defining the health-related industry sectors for this study, as well as their expert recommendations on specific firms and associated informants to include. Practice areas that were consulted within PwC included health information privacy and security, healthcare industries, pharmaceuticals and life science, healthcare IT and analytics, and health industries’ customer relationship management.

Based on guidance received from these 12 exploratory expert interviews, the choice was made to use the medical technology (or medtech) industry for the industry research part of this work, specifically including the sectors of pharma-life science, medical devices, and healthcare IT. PwC practice experts offered eight specific firm-level recommendations for this study (n=8), with a specific suggested informant for each. Depending on the company, the industry sector and the size of the enterprise, informants’ job titles included CEO, senior vice president, chief technology officer, and chief scientific officer. In the end, the industry sample included eight medtech industry executives representing organizations of varying sizes, ranging from less than $1 million to over $17 billion in annual revenue. Half of the resulting eight interview informants are current PwC clients of the strategy consulting practice.
The second stage was to engage the identified informants. The PwC HRI senior manager assigned to oversee the study invited each of the eight study participants by electronic mail for a 30 minute telephone interview (Appendix B). The PwC HRI working hypothesis for conducting this study was shared in the invitation and was stated as follows: “to deliver on consumer expectations for convenience and value in the new health economy, healthcare companies need the right mix of IT/digital tools to accelerate innovation in R&D and across the business as new entrants to the industry start to chip away at the market. Industry leaders are investing in emerging technology platforms, social, mobile and cloud technologies, R&D analytics, new skill sets, and data-sharing relationships to help them achieve breakthrough innovation faster.” All eight interviews were conducted over the telephone within a timeframe of 30 minutes each. There were no non-responders. Further details on the interview guide are described under the data collection section below.

c. Development of interview tools

Interview questions for both the academic and industry elements of the research were drawn from the key themes of knowledge generation, diffusion and use described in the literature review, and drawn from the six-generations of firm-level innovation models. These overarching themes contained within them technology push, market pull and coupling; internal-external idea generation and path-to-market pathways (inbound-outbound innovation); and integration/parallel development. Additional themes were identified specific to the academic and industry research elements respectively, based on existing measurement schemes and reference metrics/measures associated with research
valuation and innovation assessment. The methods associated with this are described under the documents and archival records section in this work.

With reference to these key themes, an interview guide each was created for the academic-facing and industry-facing interviews. These topic guides ultimately aimed to gather knowledge from decision makers on metrics and measures for assessing the economic value generated by research, as well as on the concrete application of these tools in organizational decision making and assessment. Prior to the interviews, they were shared via e-mail with the interviewees as part of their invitation (Appendices A and B).

While the interview guides served as an outline for the interviews, the interviews themselves were not rigidly confined to this structure or content. Rather, the topic guides directed general attention towards the key concerns of this study while also enabling respondents to introduce potentially unforeseen issues, provide their alternative viewpoints and explanations, and cover additional relevant aspects. Prior to use in the interviews, each topic guide was reviewed by the director for each element of the study, together with input from the respective National Academies Committee and PwC experts.

d. Data collection

This section describes document review, case study and interview data collection methods, including the development of interview tools and techniques.
i. Documentation and archival records

Review of existing measurement schemes for economic assessment of research

Extensive studies have been undertaken into evaluating the impact of research, especially with regard to the economic returns on investments in research. Reviewing this existing literature was thus a key way of establishing the measures and metrics relevant to innovation and the assessment of research in that context. An extensive literature review was conducted by the researcher and the most relevant study abstracts were shared with the study director and the chair of the NAS committee on Assessing the Value of Research for consideration. This led to a final selection of the 22 most significant contemporary studies conducted both nationally and internationally on measuring research impacts and quality as these relate to assessing the economic returns on research investment. Each of the 22 reference reports were reviewed and summarized for dissemination to the committee (see Appendix C). The summaries were supported by a number of expert testimonies to the NAS committee of assessing the value of research, of which one presented by Dr. John E. Kelly III, Senior Vice President, Solutions Portfolio and Research for IBM was included in the review as well. Findings from the document review and expert testimony were used to identify the key themes associated with each element of the study, thereafter informing the development of the interview guides and the coding scheme used throughout this research.

Comparison of SBIR/STTR and venture capital proof-of-concept funding allocations

For the case study on the federal SBIR/STTR program, an assessment was performed on the federal SBIR/STTR investment in relation to private sector venture capital investments at early (proof-of-concept) stages. The number of venture capital
investments was obtained from the PriceWaterhouseCoopers MoneyTree™ Report, a quarterly study of venture capital investment activity in the United States. Data on the number of SBIR and STTR awards was obtained from the federal SBA awards database. This assessment was followed by a single case study account from Dr. Jay Kolls, professor of pediatrics and immunology and director of the Richard King Mellon Foundation Institute for Pediatric Research at the Children’s Hospital of Pittsburgh of the UPMC University of Pittsburgh School of Medicine. In addition to being a senior academic research investigator, Dr. Kolls also has STTR research funding experience. The following are key points of each of these datasets used:

1. The MoneyTree™ Report is a quarterly study of venture capital investment activity in the United States. It is produced through collaboration between PricewaterhouseCoopers and the National Venture Capital Association, based upon data from Thomson Reuters. It organizes investment information by industry sector and by stage of investment, going back to 1995.4

2. The Small Business Administration maintains an online database of all past SBIR and STTR awards. Extensive information is available on the number of awards made, the projects and topic areas receiving funding, the federal agencies making the awards, and the companies receiving funding. New data is continuously made available going back to 1983.5

Funding data was downloaded online from both the MoneyTree and SBIR/STTR

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5 Available: [https://www.sbir.gov/sbirsearch/award/all](https://www.sbir.gov/sbirsearch/award/all) [July 2015]
databases for the 5 most recent years for which a complete dataset was available. At the time this research was conducted (September-December 2012), complete SBIR/STTR data was available for all federal agencies participating in the program until 2010, and venture capital data, reported by quarter, was available until the complete year of 2011. For the most accurate assessment, 2010 SBIR/STTR and venture capital data were compared, but some references were made to 2011 venture capital data since it was available.

MoneyTree data included investment amount and number of deals, reported by investment stage (seed, early, expansion, later) for each quarter. SBIR/STTR data included the number of grants awarded and capital awarded, reported by funding phase (phase I, II) for all funding agencies for each calendar year. Annualized data tables were constructed in MS Excel and seed stage VC investments were compared to SBIR/STTR awards, evaluated by both the number of projects funded as well as the amount of capital provided.

**Review of reference technology transfer measurement schemes**

For the academic study element, a document review was conducted of the most widely used technology transfer-related measurement schemes collected by leading technology-transfer related trade organizations and thought leaders, including the Association of University Technology Managers (AUTM), the Association of Public and Land-grant Universities (APLU), and STAR METRICS. An overview description of each of these sources is provided below, a comparison of the key metrics collected by each is included in Appendix D.
1. Association of University Technology Managers (AUTM) reports and data are the most well-known source of information on technology transfer from academic and non-profit research institutions to the public. The “AUTM Survey”, known in its most current form as the AUTM Licensing Activity Survey (ALAS), was first published in 1993. The focus has been primarily on collecting information about licensing programs, but the survey has evolved in scope to include public-benefit-related questions from which certain metrics (e.g., induced investment, product sales by licensee, jobs and taxes) can be calculated.

2. The Association of Public and Landgrant Universities (APLU) is a research, policy, and advocacy organization representing 235 public research universities, landgrant institutions, state university systems, and affiliated organizations. Led by APLU’s Commission on Innovation, Competitiveness, and Economic Prosperity (CICEP), the APLU New Metrics Project was launched in December of 2011 with the goal of identifying potential new measures of university contributions to regional economies. This resulted in the 2014 New Metrics Field Guide report to increase understanding of the resources available to universities in measuring their regional economic contributions.

3. STAR METRICS (Science and Technology for America’s Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness and Science), is a joint effort involving NIH, NSF, and the White House Office of Science and Technology Policy to document the outcomes and public benefits of national investments in science and engineering research.
**Review of reference health industry reports**

To define the industry segments and communication infrastructure themes for the industry research element, a document review was completed of the 15 most relevant PwC industry analyst reports related to the topic of interest initially defined as “the role of I.T. in healthcare innovation”. Reports for inclusion in the review were identified based on a keyword search related to the topic title completed on all industry analyst reports released by the PwC strategy consulting practice since 2011. Additional reports recommended by the senior manager responsible for overseeing the study were included as well. A complete list of the reviewed reports is included in Appendix E.

Based on this review, a summary matrix was compiled of the evolving business models for each of the healthcare related industries under initial consideration (pharma-life science or “drug” companies, medical device companies, healthcare providers or “hospitals”, and healthcare payers or “health insurance companies”). Additionally, key themes associated with the evolving communication infrastructures within each of these industry sectors were identified, summarized, and supported with case examples from the literature.

**Review of reference surveys**

To further define and identify the priority categories associated with each of the communication infrastructure themes from the initial document review, a descriptive evaluation was completed on four recent PwC executive surveys, resulting in the final themes for consideration in the interview guide and coding themes. This added the 5 themes to the coding scheme including: emerging technology platforms; social, mobile and cloud technologies; R&D analytics, new skill sets, and integration.
The PwC four survey datasets were as follows:

1. **2014 PwC Global CEO Survey**: PwC’s Annual Global CEO Survey examines the avenues leaders take to address digital change. The 2014 edition surveyed 1,344 CEOs in 68 countries. Over 130 survey respondents represented the healthcare (n~63), medical device (n~28) and pharmaceutical (n~42) industries, and were considered for this analysis.

2. **2014 PwC Digital IQ Survey**: PwC’s 6th Annual Digital IQ survey examines the application of digital technology to a variety of industries in an effort to maximize value. This global survey included 1,494 respondents from 36 countries. Answers were aggregated into five regions and 11 industries. Respondents were evenly divided between IT and business leaders. Two-thirds of respondents work in organizations with revenues of $1 billion or greater and 37 percent have revenues greater than $5 billion.

3. **2013 PwC Global Innovation Survey**: Surveying approximately 2000 executives from 25 countries and 30 sectors, this dataset examines the relationship between innovation and growth. 300 of the respondents are from the US. This study is the most extensive assessment of growth and innovation to date. 107 Respondents represented the healthcare industries, covering the Pharma-medical device sectors (n~66) and the medical payer-provider (n~41) that were considered for this analysis.

4. **PwC Global Data and Analytics (Big Decisions) Survey, 2014**: Conducted by the PwC Economist Intelligence Unit, this international survey of 1,135 executives assesses the impact of the data and analytics driving the strategic
frameworks of different industry sectors. 100 Pharma and life science companies responded to the survey, which were considered for this study.

\textit{ii. Case study}

Qualitative research information and case data for the government research part was provided through a first-hand written account from Dr. Jay Kolls, professor of pediatrics and immunology and director of the Richard King Mellon Foundation Institute for Pediatric Research at Children’s Hospital of Pittsburgh of the UPMC University of Pittsburgh School of Medicine. In addition to being a senior academic research investigator, Dr. Kolls also has STTR research funding experience. Dr. Kolls provided a written account of his experience in response to a request from the Nature Immunology Journal for a commentary on the role of the SBIR and STTR programs in advancing research goals. The researcher was a collaborator on this work and elaborated on the written account from Dr. Kolls with several telephone conversations that lasted between 15-45 minutes, as well as a number of case study related email interactions, all conducted between June 2012 and January 2013.

\textit{iii. Interviews}

Semi-structured stakeholder interviews were the primary mode of data collection. Interview questions were constructed so as to elicit participants’ perspectives based on their particular experiences in academia or industry experience, and on the experiences of their institution/company in determining and facilitating the economic value of their research through specific metrics and measures. Particular points of focus were the ways in which these metrics and measures are used in stakeholders’ decision making processes.
with regard to research, and how they may affect the economic value arising from their collaborations with external organizations.

Semi-structured interviews were selected as the primary data collection method given the exploratory, organic nature of assessing the economic value relationship between academia and industry, as previously discussed in this dissertation. Semi-structured interviews enable just such an in-depth, exploratory approach and lend themselves to probing and highlighting the unexpected, particularly in the context of complex phenomena and relationships (Fontana and Frey, 1994), such as innovation systems. While a broad range of metrics associated with research valuation are readily available and tracked on both a direct and indirect basis, it is essential to understand their meaning, and the ways in which they are applied to the ethos and aims of individual organizations and the model pillars they represent. For this reason, semi-structured interviews can be seen as a highly useful tool for explaining the deeper reasons behind such metric use, as opposed to simply knowing what these metrics are and where they are used; in other words, filling in the ‘meaning’ gap behind them.

Another reason for using this approach is that it provides the opportunity to explore and identify potentially new elements of the NIS framework. While substantial scholarly work has already been undertaken into research enterprise metrics, there still exists a knowledge gap with regard to softer indicators such as the value generation associated with human capital flow within an innovation system. Semi-structured interviews, by their nature, allow for the emergence of previously unforeseen concepts.

Finally, the private nature of one-to-one, semi-structured interviews is an optimum tool for use in contexts involving sensitive information, such as the current
study that focuses on the use of metrics and measures in innovation strategy and investment allocations, which are often central to organizational competitiveness and can only be accessed following the building of trust and rapport with a company’s most senior executives. This advantage of the interview approach is supported by studies highlighting a much higher likelihood of receiving a relevant and thorough response from high-ranking stakeholders and decision makers via interviews (Mahoney, 1997) than via anonymous surveys, where typically low response rates have been recorded from this same respondent group (Hambrick et.al., 1993).

**Interview techniques**

All interviews across both study elements were semi-structured and in-depth in nature, so as to build in flexibility to gather knowledge in the relevant areas that emerged as well as those steered by the interview guides. As previously discussed, this then enabled the researcher to pursue his key interview concerns and also provided the interviewee with space to discuss what was additionally important to them. As part of the ethics of the interview procedure, it was emphasized to interviewees that they could choose not to answer set questions and to feel free explore other themes or nuances of concerns to them. Both interview guides had built in prompts acting as examples to help steer interviewees towards focal points, and probes to encourage them to delve deeper into any one topic. The initial document review stage of the study yielded knowledge of reference metrics and measures that were then integrated into the interview guides to ensure that conversations with respondents extended beyond focusing on the specific portfolio of metrics and measures used by that interviewee’s organization. This also proved important in encouraging respondents’ applied rather than theoretical feedback as
to how these metrics and measures were concretely used within the innovation value assessment framework.

Prior to the commencement of each of the academic telephone interviews, permission to record the interview was requested from each respondent. This was given by all respondents, and so all of the academic interviews were recorded.

Because of the sensitive and sometimes proprietary nature of the interviews with executive decision makers in industry, the interviews were not recorded but extensive interview notes were taken for analysis.

e. Data analysis and validation of findings

i. Data analysis

Qualitative research is based on inductive logic. Its goal is to gain a deeper understanding of a person’s or group’s experience through the discovery of patterns, themes and categories leading to specific findings (Patton, 2005 and Denzin, 2011). The primary purpose of this research was to characterize how academia and industry assess the economic value of research utilizing metrics and measures within a national innovation system framework.

Recorded interviews and interview notes were transcribed and anonymously entered into computer software that manages and codes qualitative data, Nvivo10 (QSR International, Australia). For the industry interviews, company references were preserved for report case study purposes. The academia interviews were first classified according to certain fixed variables, for the purposes of eliciting any trends across the different institutions. These variables were: whether the institution was public or non-public; the
amount of annual research expenditure (small, medium or large); the annual license revenue received (small, medium or large); and whether or not the institution had a medical center.

Data from both the academic and industry research elements of the research was then analyzed separately using content analysis, which seeks emerging patterns, themes and categories in the data. This was done with reference to the coding frameworks listed in Appendix F, based on the literature and initial document review. As new concepts and other relevant themes emerged, such as metric or measure categories, partnership types, governance and strategy decisions, different stakeholders, measurement frameworks, and return on investment, they were iteratively added to the coding framework to make this more nuanced as the analysis progressed. Once the themes and categories were exhausted and the framework completed, a confirmatory stage was performed for each part of the research using deductive analysis. An expert review of the content was also conducted by the National Academies committee and PwC Health Research Institute senior staff, in order to validate the findings.

In a final step all 15 interviews from both the academic and industry research elements of the study were coded using a meta-coding framework of the two combined. Here, all the identified innovation metrics and measures were categorized as universal input, output, or outcome metrics based on the literature for inclusion in the model.

Descriptive statistics, figures, and graphs for the government case study and the industry research element were performed using Microsoft Excel 2013.

ii. Validation of findings

A key concern with qualitative research is ascertaining the validity of findings.
For the current study, a number of techniques were used for this purpose, specifically aiming to ensure appropriate data handling and accountability throughout the analysis (Patton, 2005).

To begin with, interviewees’ feedback, or respondent validation, was consistently applied throughout the interviews to improve the accuracy, credibility, validity and transferability of the study by restating or summarizing information, and then questioning the participant to determine accuracy.

During the analysis stage, deviant case analysis was performed in order to refine the analysis until it could explain or account for a majority of cases by searching for and discussing elements of the data that did not support or appeared to contradict the emergent patterns or explanations. For example, the response of some academic informants who commented that their metrics were well aligned with their institutional mission and goals, but could not substantiate this with the specific use of metrics and measures, was excluded from analysis.

Two types of data triangulation were also employed to check data validity: firstly, comparing the metrics and measures derived from the document review against interview information; and secondly, comparing the two sets of interviews (academic and industry) against each other to check the consistency of the data. The expert external review was then used as a further method of validating these findings.

Finally, a systematic coding framework was used based on the national innovation system determinants (Appendix F), to ensure the validity of inferences and conclusions.
V. RESULTS

This chapter presents the results of this research, including a synthesis of the information gathered from document review, key informant interviews and case studies. The chapter is organized by the component parts of the research and its associated hypotheses, including government (H1), academia (H2) and industry (H3), following the flow of the research design (see Figure 15). All informant interviews were evaluated as a single dataset for a determination of universal input, output, and outcome metrics and measures to assess the economic value relationship between academia and industry within the national innovation system framework.

a. Document review: value assessment frameworks

i. Review of existing measurement schemes for economic assessment of research

To guide this work, a document review was completed of the 22 most significant contemporary studies conducted both nationally and internationally on measuring research impacts and quality as these relate to assessing the economic returns on research investment, and were supported by a number of expert testimonies to the NAS committee of assessing the value of research, which were also considered for this review. Dimensions of particular interest were measurement schemes in other nations, medical research, and spanning government, academia, and industry, as detailed in turn in the remainder of this section. This review was undertaken in order to identify the key themes associated with each element of the study and inform the development of the interview guides and coding schemes used throughout this research. Complete references and annotated bibliographies of all the reviewed studies are included in Appendix C.
Other nations

Measuring the ‘real’ returns on research has proved a challenge in many nations alongside the United States, including Australia, Canada and the United Kingdom. Studies dealing with these challenges generally conclude that there is, at present, a theory gap in reliably predicting the probability with which certain research activities will generate scientific or societal advances (Council of Canadian Academies, 2012).

Despite that fact that metrics attempting to predict this relationship have been developed across multiple disciplines and countries, the construction of universal evaluation systems has met with numerous obstacles, particularly given international variations in policies, research funding approaches, and research missions (National Research Council, 2006). The UK’s Council for Industry and Higher Education highlights three other key aspects that may impede reliable assessments of publicly funded research impacts: (1) the influence of complementary investments (e.g., industry funding); (2) the time lag involved in converting knowledge to outcomes; and (3) the skewed nature of research outcomes, in that 50-80 percent of the value created from research tends to result from 10-20 percent of the most successful projects. The authors of the latter study suggest that this last challenge may be overcome by analyzing the research and development (R&D) phase/type of each funding agency portfolio and then assessing the ethos and approach of individual researchers in response to it, in addition to using outcome-based measures (Hughes and Martin, 2012).

However, it has also been posited that, even when reliable and valid metrics are constructed, their very use may induce certain positive and negative behavioral changes among researchers and research institutions, given that such metrics are typically used to determine which research projects should be funded (OECD, 2010). For example, studies
of Norway, Australia and the UK have indicated that requiring publication volume to be embedded in the grant review process led to a significant increase among institutions’ publication output, but sometimes also meant a decline in publication quality as researchers traded quality for volume (Butler, 2003; Moed et al., 1985; OECD, 2010). While indicators relating to both the quality and output of research publications have tended to be seen as useful in nations outside of the U.S., two concerns have arisen: the potentially subjective definition of a “high-quality” journal, and the difficulty of determining whether publication in widely cited and renowned journals is in fact better than that in more specialized or regional journals (Council of Canadian Academies, 2012).

Research impact metrics based on training and collaboration, such as the number of graduates and their flow into specific industry sectors, firms or laboratories, have also been found to be useful, although not without their own challenges. For example, given that these metrics are essentially output focused, emphasizing them could arguably promote the pursuit of “research active” disciplines/departments while leading to the dissolution of less output-driven disciplines (Evaluation Associates, Ltd., 1999; McNay, 1998; OECD, 2010).

Another commonly used metric is the amount of external research funding that an institution attracts as a complement to its public grants. They key problems with assuming this as a metric, as experienced by the UK and Australia for example, are: institutions’ subjective reliance on expert judgement in funding decisions; the potential influence of profit-motivated industry investments on research investments (such as pharma funding for drug safety evaluations); and the risk of researchers to be rewarded
for more inefficient and thus costlier budgets (Council of Canadian Academies, 2012). Finally, esteem-based indicators have been used as metrics in certain nations. These include the status of previous educational institutions attended by students, the number of awards or other prestigious recognition obtained by the institution. While useful these metrics categories have been criticized as overly subjective and possibly influenced by external factors such as personal choice and location rather than the institution’s quality per se (Council of Canadian Academies, 2012; Donovan and Butler, 2007).

**Medical research**

Economic returns on investments arising from medical research in particular have been a focus of certain major studies, as summarized in appendix C. A seminal one is the Lasker Foundation funded study and report, “Exceptional Returns: The Economic Value of America’s Investment in Medical Research” (Passell, 2000). This study calculated the economic returns on the $45 billion (in 2000 dollars) from both public and private sources annual investment in medical research, to be worth a total of $57 trillion in the form of new health products, diagnostics and treatments. While this metrics model has since been replicated in Australia, the UK and Canada, there remain certain key concerns associated with these value calculations, as follows:

- **Measuring the economic returns on research investments**— these measures include using a benefit/cost ratio of the value of health benefits to the costs of research; a return on investment (ratio of the amount by which health benefits exceed research costs to research costs); an internal rate of return (IRR), that is,
the rate of return for which net present value is zero; and the discount rate at which the net present value of research costs equals the net present value of health benefits over time. Challenges with this approach have been noted in the literature review.

- **Valuing health benefits**—these benefits are calculated Examples include using a by assigning monetary value for one year of life, or a quality-adjusted year of life, considering direct cost savings for health services or, indirect cost savings when improved health leads to increased productivity increases; and, or increases in gross domestic product or other economic gains. This approach has proven challenging in areas such as mental health research where Disability-Adjusted Life Years (DALYs) decline over time resulting in a negative value for the associated research (Access Economics, 2003, 2013).

- **Measuring research costs**—key questions arising here include how these costs are determined; how the infrastructure is accounted for; the extent to which public and private research costs can be compared; and accounting for the effect of research failures, which, as noted in the literature review, may nonetheless advance knowledge.

- **Time lag**—there is a need to determine an acceptable length of time that can pass between the research phase and the actual health benefits occurring as a result.

- **Global benefits**—a major problematic here is identifying the global health benefits that accrue from U.S.-based research and, conversely, the health benefits that accrue to the U.S. by virtue of other countries’ research. Determining how
such international transfers of research knowledge should be accounted for remains a source of contention.

- **Attribution**—in undertaking to measure how precisely medical research ultimately impacts citizens’ health, it is inevitably difficult to disentangle how much of this potential health improvement can be attributed to that research and the concurrent improved health care, as opposed to people’s improved hygiene, diet and other behaviors. Likewise, it is challenging to discern the extent to which behavior changes that positively impact health can be attributed to behavioral and social science research. Finally, it remains to be seen how best the contributions of behavioral and social science research to improved health can be distinguished from those of medical research on therapeutics.

- **Intangibles**—at a more overarching level, it is difficult tangibly to discern the extent to which research in a health care system can then increase that system’s capacity concretely to use the research findings (Belkhodja et al., 2007).

**Government**

Measuring the impact of federal research funding programs fundamentally aims to assess their effectiveness and put guidelines in place as to how to choose the optimum program for maximizing societal returns. To this end, there are typically two stages actioned by federal agencies; firstly, selecting research funding recipients through prospective assessment; and secondly, retrospectively evaluating the performance of those funded.

Several federal agencies, especially the National Institute for Standards and Technology (NIST), part of the U.S. Commerce Department, have conducted economic
impact studies to assess the value of the research they have funded. For example, NIST has conducted 40 such retrospective studies over the past 20 years, for which it applied metrics drawn from a set of three alternative measures in figure 16 (Tassey, 2014):

- Measures guiding public R&D policies which, in turn, determine resource allocation, including those influencing firms’ and businesses’ investment decisions (i.e. process measures);
- Measures guiding private industry investments in R&D, such as return on investment, benefit-cost ratio, and net present value (i.e. output measures);
- Measures enabling the evaluation of research and innovation systems, such as employment growth, increases in productivity, and other economic and societal impacts (i.e. outcome measures).

**Figure 16. Influences of processes, outputs and outcomes on research impact.**

As depicted in figure 16, assessing impact and role rationalization typically form part of a recursive evaluation process. Both elements must be accurately modelled, importantly taking into account the ways in which they interact. Within this context, the conceptual argument for federal R&D funding (i.e. the existence of market failure) must be assessed through economic analyses of industry investment patterns, with a view to highlighting the source of trends pointing to underinvestment. Such analyses are intended to lead to the design and implementation of policy responses which, in turn, are followed by further economic impact assessments at regular intervals. The findings from these assessments are then used iteratively to feed back into adjusting the existing policies and associated budgets.

In the United States, neither Congress nor the Executive Branch has an institutional mechanism in place to enable comparisons of research performance across different disciplinary fields, or for R&D portfolio analysis. Similarly, not all federal agencies have resources specifically dedicated to retrospective evaluation. For example, NIH tends to undertake process and outcome evaluations of the external research organizations it has allocated funds to both early on and at the five-year point of these funding programs, rather than when the programs have been completed. Similarly, a requirement of the NSF is compulsory evaluation of its research programs such as the 10-year Industry-University Cooperative Research Center Program, along with some of its educational grant programs. The outputs of both of the latter evaluation efforts are descriptive statistics and case studies; while useful for describing how the programs unfolded and the lessons learned, they arguably rarely yield insights that can be applied to measuring tangible impact.
The metrics and measures most commonly used by agency-specific funding programs include STAR METRICS, the Research Portfolio Online Reporting Tools, the Scientific Publication Information Retrieval and Evaluation System, and the Electronic Scientific Portfolio Assistant. Government-wide tools include the Government Performance and Results Act (GPRA) and the Program Assessment Rating Tool. As longer-term outcomes are less easily quantified, the focus of the implementation of these tools has largely been on measuring short-term outputs.

Peer review and assessment tends to be the most widely used mechanism for the prospective evaluation of research grants and contract proposals. While these means have been critiqued on the basis that they may dilute expertise (Alberts et al., 2014), peer review is generally considered the best available mechanism.

**Academia**

The initial document review of the 22 reference reports in Appendix C details the use of metrics to evaluate both research universities’ regional economic impact and the general use of metrics to assess the extent and impact of university technology transfer. A number of specific technology transfer measurement schemes emerging from this review are described later in this chapter specifically with regard to the academic pillar of the evaluation framework.

**Use of metrics to evaluate the regional economic impact of research universities**

While numerous public research and education institutions have undertaken useful research into their impact on local, regional, and state economies, these studies are arguably weakened by not addressing the key question of what would have happened with these economies had the university not interacted with them. That is to say, they
rarely contain comparisons with a ‘control’ area that lacked a similar intervention.

Recognizing this gap in tangible impact understanding, key metrics and measures most commonly derived from university economic impact reports relate to the economic benefits arising from universities’ human capital, i.e. faculty and alumni engagement and performance. For example, the study “Entrepreneurial Impact: The Role of MIT” (Roberts and Easley, 2009) analyzes the economic impacts of companies founded by MIT alumni. Based on a 2003 survey of all living MIT alumni, and revenue and employment figures updated to 2006, the study concludes that all of the companies combined (excluding Hewlett-Packard and Intel) would theoretically employ 3.3 million people and generate annual revenues of $2 trillion, making this the 17th-largest economy in the world.

Use of metrics to monitor university technology transfer

Various metrics are used by universities to monitor the dissemination and uptake of technology resulting from their research (see results section c. Academia). The metrics most commonly used include inputs such as collaborations, intermediate outputs such as innovation creation and knowledge acceleration, and final impacts such as qualitative outcomes or economic development. While extensive, these have been criticized for failing to take into account key formal and informal channels of knowledge flow to and from universities (Walsh et al., 2003a, b), such as the trajectories of trained degree holders, faculty publications, faculty and student participation in conferences, science laboratory sabbaticals, and faculty consulting services. From the in-depth document review, it can be argued that the optimum technology transfer metric to use for a particular university and research project depends largely on the goal of the university’s
technology transfer itself. Such goals may include an increase in the university’s revenue through licensing, supporting small firms, capacity building university entrepreneurs, attract and retaining faculty members specializing in entrepreneurship, and supporting regional development, among others. It is here that a disconnect has often been found; namely, between the selection of the most appropriate metrics and the university’s broader strategic goals. This disconnect, in turn, can complicate the use of the chosen metrics in analyzing performance or creating benchmark data to then draw comparisons between different universities.

**Industry**

In the context of industry, research impact metrics are considered essential tools for ensuring continued growth and competitiveness. Despite this, most research funding decisions made in industry tend to be based much more on executive judgment than on quantitative metrics. In addition, there appears to be a shift in the weight from more qualitative to quantitative data as projects/programs transition long-term research to near-term development. While the long-term goals of industry with regard to research differ in many from those in government, strategic planning is an overarching method to identify gaps in existing platforms. An example of such strategic planning would be IBM’s reliance on the Global Technology Outlook process (GTO). This comprises an annual, corporate-wide effort to forecast future trends and internal technology shifts based on foreseen technology developments. GTO’s key metrics aim to quantify how many future technology disruptions and business trends will be missed, and how many will be identified and applied. While quantitative in terms of data output and presentation, these predictive metrics rely heavily on more qualitative inputs, such as the judgment of
experienced managers and scientists. GTO metrics applied for the shorter term, i.e. a 2-5 year product time horizon, include product competitiveness and market share. As part of its overall impact measurements, IBM also measures the intellectual property it generates by taking stock of its patents and other means, as well as its capacity to continue scientific IT exploration by tracking the number of the company’s key publications, recruitment and retention of top scientists, and assessing its impact on various scientific disciplines.

Some of the most commonly used industry metrics related to R&D-driven innovation and competitiveness include total R&D investment and R&D intensity (the R&D to sales ratio), often used by individual firms to benchmark against other competitors or industry sectors. The global top twenty of industrial total R&D spenders for 2015 was led by Volkswagen at $15.3B, followed by Samsung at $14.1B, Intel at $11.5B, Microsoft at $11.4B and Roche at $10.8B. The top 20 R&D spenders are roughly divided evenly between the healthcare (7 companies), software and internet, computing and electronics (7 companies), and automotive (5 companies) industries. Two out of the top five, and twelve out of the top 20 R&D spenders, are American. Of the top 20 total R&D spenders in 2015, AstraZeneca was the most R&D intensive with an R&D/sales ratio of 21.4%, followed by Roche at 20.8% and Intel at 20.6%. Volkswagen, the largest total R&D spender, had an R&D intensity of 5.7% (PriceWaterhouseCoopers, 2015).

**ii. Review of reference technology transfer measurement schemes**

In order to monitor the development of technologies transferred from research and development (R&D) laboratories, universities collect multiple types of metrics, of which the six most common are: invention disclosures, patent applications, patents issued,
license agreements, startups, and license revenue per million in R&D expenditures (West 2012). These and similar measures are most often administered and disseminated via trade organizations and federal measurement collaborations. For the purposes of the qualitative element of the current research, three of the most prominent and timely metric schemes collected by influential trade organizations and federal initiatives were evaluated, as detailed in the remainder of this section. In doing so, the data structure, value, quality, and accessibility of each metric were considered.

**AUTM Licensing Activity Survey**

AUTM surveys are the most common go-to source of information on technology transfer from academic and non-profit research institutions. First published in 1993, the AUTM Licensing Survey contains data on participating respondents dating back to 1991. The main metrics employed in the survey are: the number of invention disclosures the technology transfer office receives from faculty; the number of patents applied for and granted; the number of licenses executed; and the amount of revenue derived from licenses, legal settlements, investment liquidation, sales of IP rights, and related indicators. Since its inception, the survey has evolved to include some product and public-benefit-related questions within its remit, from which other metrics such as induced investment, product sales by licensee, and jobs and taxes, can also be calculated.

For the most recent year, survey data was provided by 191 institutions that responded to the AUTM 2014 licensing survey. The respondents included 163 universities, 27 hospitals and research institutes, and one third-party technology

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6 Available: http://www.autm.net/resources-surveys/research-reports-databases/licensing-surveys/ [February 2014]
investment firm. Some aggregate metrics for the FY2014 dataset include a total of 5,435 licenses executed (up 4.5% over prior year), 1,461 options executed (up 7.7%), 549 executed licenses containing equity (up 17%), 914 startup companies formed (up 11.7%), 4,688 startups still operating as of the end of FY2014 (up 11.4%), 965 new commercial products created (up 34.2%), and 6,363 U.S. patents issued (up 11%).

A major challenge of applying AUTM survey data is that of using it for trends analysis. This is because AUTM survey participation is highly variable year over year, with the possibility of deliberate non-participation skewing trend data (e.g. in the case of a university choosing not to respond to the survey in a year of weak licensing activity). For this reason, the cross-sectional data reported for a particular year (e.g., 6,363 U.S. patents issued in Fiscal Year 2014) should be seen as more reliable.

Another criticism of the scope of AUTM data is its emphasis on the primacy of the volume of technology transfer activity over quality and efficiency, meaning that it is less likely to consider important factors such as the timeliness of research outputs, the extent of marketing outreach, the nature of collaborations with faculty inventors, and economic or social impact. While a substantial amount of social impact information is available through the AUTM “Better World Project” compilation of cases (another data source maintained by AUTM), there is no systematically collected evidence base that enables rigorous conclusions to be reached regarding the reasons for why different institutions’ performance varies to the extent that it does on key metrics. Furthermore, there is a significant knowledge gap in the literature regarding how technology transfer itself concretely occurs; that is, via publication, teaching, networking, consulting, student placement, and collaboration. As a result, these channels are not only undervalued but
also under-evaluated (Merrill and Mazza, 2011).

Results from the annual AUTM Licensing Activity Survey are released in an annual report that is made available freely to members of participating institutions. It is also publically available for purchase through the AUTM website. Underlying data from all past surveys is available through the AUTM Statistics Access for Tech Transfer (STATT), a searchable, exportable online database containing all the academic licensing data collected by AUTM from participating academic institutions since 1991.

**APLU New Metrics Project**

In December 2011, the Commission on Innovation, Competitiveness, and Economic Prosperity (CICEP) of the Association of Public and Landgrant Universities (APLU) launched its New Metrics Pilot Project, with the goal of comprehensively collating and finalizing the optimum ways of measuring university contributions to regional economies. 32 higher education institutions participated in identifying these and informing the feasibility study of a range of potential data elements. Through this process, an initial set of over 50 metrics was narrowed down to 20 that were considered the most valid and accessible. These 20 “CICEP New Metrics” have been proposed for near-term implementation by APLU, and for consideration by the National Science Foundation (NSF) National Center for Science and Engineering Statistics (NCSES) (APLU, 2013). They include:

- Relationships with Industry: sponsored research by industry
  - Number of grants, contracts and sub-agreements (including federal pass-through dollars) from private sector entities (including consortia, trade associations, etc.)
- Dollar value of sponsored research expenditures by private sector entities (including consortia, trade associations, etc.)
- Number of sponsored research projects by industry sector (including the source/explanation of industry sectors used by each institution)
- Dollar value of sponsored research expenditures by industry sector
- Number of unique private sector entities funding research grants and contracts (including consortia, trade associations, etc.)
- Relationships with Industry: human clinical trials
  - Number of trials conducted by phase
  - Number of subjects participating in clinical trials
  - Dollar value of sponsored research expenditures for/on clinical trials
  - Number of protocols approved during time period
  - Number of trials initiated during time period
- Relationships with Industry: service to external clients
  - Number of organizations served
  - Number of companies providing on-site technical services
- Developing the Regional and National Workforce: student employment on funded projects
  - Number of students paid through externally funded grants or contracts
- Developing the Regional and National Workforce: student entrepreneurship
  - Number of entrepreneurship courses/programs
  - Number entrepreneurship courses/programs requiring a capstone project (e.g. business plan, elevator pitch, etc.)
  - Number of student start-ups associated with courses, programs, competitions, clubs, or other university-affiliated organizations
- Developing the Regional and National Workforce: alumni in the workforce
  - Average wages of alumni living in-state
- Knowledge Incubation and Acceleration Programs: incubation and acceleration program success
  - Number of incubator/accelerator full time equivalent employees
- Knowledge Incubation and Acceleration Programs: ability to attract external investment
  - Dollar amount of (equity) capital raised by clients and graduates
  - Dollar amount of funding received from federal, state or foundation sources, state or local matching programs, or other non-private sources.

To promote access to and adoption of the 20 CICEP new metrics, APLU is coordinating with organizations such as the NCSES that already collect, or are planning to collect, similar data from universities in order to adopt the new CICEP metrics. In 2014, the APLU published the CICEP New Metrics Field Guide around the new metrics to help economic engagement leaders identify the right measures and indicators to use in evaluating the success of their economic engagement. This publically available report aims to serve as a guide for measures and metrics that may align with the kinds of contributions that particular universities aim to make, prioritize campus efforts to collect data on these measures, and set goals for improving institutional measures (APLU, 2014).

**STAR METRICS**

Science and Technology for America’s Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness and Science, otherwise known as STAR METRICS, is a collaboration between the National Institutes of Health (NIH), the National Science Foundation (NSF) and the White House Office of Science and Technology Policy, aiming to capture and codify the outcomes and public benefits of national investments in engineering and science research.

The data collection of this joint effort was in its initial phase (Level 1) at the time of this evaluation, having begun in 2010 with a pilot seven universities. The activities at the time of review relied on a restricted number of data fields from existing university
administrative databases, with all information and sources anonymized. The goal of Level 1 is to make the data agile and consistent enough to enable it to report on the impact that federal research and development (R&D) spending has had on job creation. This goal necessitates two steps: (1) collating and automating the standardized reporting of information contained in university administrative records relating to grant payment, and (2) creating an investigator rather than an institution-centered dataset to enable the analysis of federal research programs.

Level I STAR METRICS data are divided into three files, each of which monitors a particular stream of federal R&D expenditures by performing institutions. Each institution quarterly updates each file. Once cleaned and put together, these three files yield 14 data items referencing a wide variety of R&D actors. Arguably, potential value can be derived from cross-institutional comparisons of these data and from job creation estimates undertaken by the NIH and other agencies (National Research Council, 2014).

Given its facilitation of micro-level comparisons both of the funding and internal infrastructure of academic R&D across a wide range of institutions, STAR METRICS arguably provides a unique source of relevant information on the ways in which federal R&D money flows from performing institutions into the larger economy. It can also generate important information on the types of jobs supported by federal R&D at performing institutions, and on how research collaborations occur within the academic context. Furthermore, linking STAR METRICS with other key sources of information, including examinations of economic and labor force dynamics, could generate additional value by creating new and more accurate estimates of universities’ direct and indirect economic impacts courtesy of federal R&D funding (National Research Council, 2014).
As of January 1st 2016, the federal collection of institutional data and subsequent production of Level I reports was halted due to a reallocation of resources in favor of the Federal RePORTER measurement scheme. Level II of the initiative will be pursued through the Federal RePORTER tool, developing an open and automated data infrastructure that will enable the documentation and analysis of a subset of the inputs, outputs and outcomes resulting from federal investments in science.

**Comparison between reference measurement schemes and dissertation sample frame**

A comparison of the key metrics collected by each measurement scheme is included in Appendix D, as well as a comparison between the participating organizations in each measurement scheme and the sample frame for this dissertation. In summary, it can be said the AUTM survey data primarily considers the transactional data directly or indirectly leading to university earnings through industry engagement. STAR METRICS is primarily interested in human capital, especially through job creation data. The APLU new metrics program is most interested in outcomes associated with university engagement, spanning both transactional and human capital themes.

Given that AUTM 2014 Licensing Activity Survey data was used with recourse to the STATT database to establish the sample frame for the academic research element of the current dissertation, there is complete overlap between them. 16 universities (40%) are shared at least at the systems level between the dissertation sample frame and the Level 1 STAR METRICS participants that could be identified. Eight institutions (20%) are shared at the systems level between the APLU New Metrics and the dissertation sample frame. Five institutions are shared at the systems level between the dissertation sample frame and all three of the reference measurement framework.
iii. Review of reference health industry reports

Following the implementation and enforcement of the Affordable Care Act (ACA) in 2014, new standards and opportunities have rapidly been remolding the $2.8 trillion US health sector. Health related industries across the spectrum must now adapt to accelerating innovation, more informed and empowered consumers and, most notably, growing competition from non-traditional players (PwC, 2013). This dynamism and change has brought with it the chance - and need - for communication infrastructures that maximize innovation returns to be applied like never before. Innovation across the healthcare industry continuum is increasingly being facilitated by new digital accelerators that transcend geographical limitations, making this industry a keenly interesting study perspective for the industry research element of this dissertation. With that in mind, and to rigorously evaluate the innovation-focused communication infrastructures tied to this industry element, it is necessary first clearly to define the specific industry sectors of interest within healthcare. For this purpose, and to guide the survey review and qualitative interview stages of the research, it was important to gain insight into both the documented leading digital innovation drivers across the health industries, and the validity and strength of these communication infrastructure motifs in driving business success within and between the possible industry sectors of interest.

To this end, the researcher evaluated 15 recent PwC industry analyst reports examining diverse and relevant topics related to innovation and industry trends in the health related industries. These were reviewed for both themes regarding digital innovation and the specific accelerators/dynamics affecting each sector, as well as specific case studies/evidence supporting these drivers. To narrow the scope of the industries for this research, four health related sectors were initially considered: the
medical device sector, healthcare providers (a.k.a. hospitals), the pharma-life science sector, and healthcare payers (a.k.a. health insurance companies). Appendix E shows a list and summary matrix of the reviewed reports. The results from the document review on each of these four areas are as follows.

**Pharma companies** have traditionally marketed drugs to physicians, as the latter have been the principal motivators of drug uptake among patients. Over time, price increases and the need for transparency about drug quality has placed growing pressure on drug manufacturers. Pharmaceutical companies are thus increasingly called on to re-evaluate their pricing models and develop new ways to add value, which may be done by forming co-ventures with new market players targeting patients with similar diseases or conditions.

The historical focus of **medical device companies** has been more on selling to providers (hospitals) rather than consumers (patients). Increasingly, however, the value of such devices lies not only in the actual product itself but also in how medical companies integrate the information and services around them in order to solve the larger concerns of both providers and consumers.

Traditionally, **healthcare providers** as an industry have tended to be localized in scope, with limited pressure exerted by the market and external competitors. In line with this, the bulk of healthcare services provided has typically been paid for through fee-for-service arrangements between hospitals and payers, with little involvement on the part of the end user, i.e. patients. However, influenced by the recent ACA, a new health economy is forming that increasingly incentivizes value over volume, in that providers are called on to manage patients’ health more holistically.
In previous decades, the workplace has been the primary provider of health insurance for the majority of U.S. citizens, often with limited options. This is changing under the influence of ACA as health insurance is becoming a new open market, whereby individuals can select from a myriad of insurance options. Payers must thus prepare for this industry shift from wholesale to retail, with the interests of consumers at heart.

Common factors affecting innovation in healthcare across these four industry sectors are crowd sourcing, collaboration management, SaaS & cloud, social/mobile tools, clinical innovation, and big data. These drivers are fundamentally altering the ways in which health organizations interrelate and do business, allowing companies to reach more people with greater speed and efficiency, and arguably making health interventions faster, cheaper, easier and more meaningful for the customer than ever before. Ultimately, these technological advances are mandating the health industry to adapt its business models in order to be able to comply with increasing consumer expectations of value and convenience.

Based on an extensive review of the referenced literature, it was noted that the communication infrastructures affecting research-driven innovation are most developed and fastest growing among the pharma-life science, medical device, and healthcare provider industry sectors, collectively defined as the “medtech industry” for the purposes of this dissertation. While equally interesting, the communications infrastructure involving payers is much less focused on research-driven innovation, and much more on consumer-facing marketing and sales; as such, this sector was deemed to be outside of the scope of this dissertation.
b. Document review: databases and surveys

i. Comparison of SBIR/STTR and venture capital proof-of-concept funding allocations

In 2010, the SBIR program had $2.1 billion allocated to it by federal government, and the Small Business Technology Transfer (STTR) program had over $250 million. Using these funds, the two programs collectively funded 4,897 phase I grants and 2,207 phase II grants for early stage funding of novel technologies (SBA, 2015c). In comparison, at the seed funding stage (which is similar to the proof-of-concept research funded by the SBIR/STTR programs), venture capitalists (VCs) provided $1.68 billion in seed stage funding in 2010, spread over 408 small businesses. By 2011, such seed stage venture capital investments had decreased by 38% compared to 2010, to $1.048 billion (PriceWaterhouseCoopers, 2012). As indicated by this, VCs are funding fewer initiatives and using their investing dollars for the maintenance of their existing portfolios. With private investment funds strapped, therefore, SBIR grants are arguably playing an increasingly important role for small business owners seeking early stage funding. Figure 17 illustrates SBIR, STTR and VC capital availability in 2010, as this was the most recent year with complete data available for SBIR and STTR.
As shown in figure 17, of the $4.07 billion of combined SBIR, STTR and VC seed capital that can be considered “proof-of-concept” funding available in 2010, approximately 60% was provided by the SBIR and STTR programs, indicating that these federal programs have provided the most significant proportion of U.S. seed capital in this time period. SBIR and STTR collectively made 7,104 awards, compared to 396 seed stage investments by venture capital. Overall funding patterns show how VC tends to invest heavily at later, potentially lower risk stages. While SBIR/STTR funds only account for about 10% of the $25.8 billion combined SBIR, STTR, and VC investment
pool in 2010, it is clearly the dominant source of proof-of-concept funding.

\textit{ii. Review of health industry surveys}

To help guide the key themes for the medtech industry executive interviews and to support the subsequent qualitative analysis, the results from four recent reference surveys conducted by the PwC Health Research Institute were evaluated for relevant information pertaining to the importance of innovation to the industry, the types of digital investments industry executives are making, and their relevance within the medtech industry and its constituting sectors. A descriptive evaluation was performed on the survey result summary tables, which were made available in MS Excel. The results of this evaluation are provided in the following section.

\textbf{2013 PwC Global Innovation Survey}

The 2013 PwC Global Innovation Survey indicates that drug and device companies are staking more on innovation than other industries are. However, in their planning for the following year, nearly half are prioritizing traditional product innovation rather than service and business model innovations that could arguably help them assert and boost their value beyond the safety and efficacy of their drugs and devices alone. Investment in digital tools has become common among leading drug firms, which are increasingly turning to this as a means of generating new revenue streams from their data, optimizing outcomes, and creating more rigorous engagement strategies with patients (Fig.18).
PwC’s Global Innovation Survey shows that new digital market players are more likely to:

- View themselves as innovation pioneers;
- Have obtained a greater proportion of annual revenue from key new products and services released onto the market over the past year;
- Innovate on their business models in a way that allows them to create new services rather than a single product;
- Harness the power of social media to boost their innovation efforts and enable them to collaborate with competitors in order to deliver innovative products and services.

This survey also reveals that approximately 25 percent of executives in drug and device companies report that new market entrants, often large, operationally strong...
companies that previously did not engage with the healthcare sector, are influencing their strategic agendas. Open innovation was most frequently named by drug companies as the key mode likely to generate the most growth –more so than incubators, design thinking, and employee autonomy to develop innovative ideas. Device companies ranked open innovation a close second. On average, however, device executives said they currently co-create only 21-30% of their products and services with external partners. Culture emerged as a barrier to innovation, as half of drug and 57% of device companies cited the lack and effort of creating an innovative culture as a barrier to embedding original ideas.

Social media was found to be a highly valued and strategic resource, and also an innovation catalyst, as reported by nearly half of the executives surveyed. Investment in social media for the purposes of internal communication and collaboration ranked among the top five areas of digital technology investment for drug and device companies. Nonetheless, the survey data suggests that the degree of effectiveness with which companies are combating traditional silos– from R&D to commercial business units–is debatable.

The survey also indicates that 43% of device companies and 69% of drug companies use social media to support informal and organic co-working platforms, but that fewer are capturing and evaluating new ideas, conducting innovation campaigns, or enabling external input in a systematic manner (See Figure 19).
Figure 19. Drug and device companies are using social media for innovation.

*SOURCE: Data from PwC Global Innovation Survey, 2013.*

While numerous device manufacturers have created smartphone apps to enable patients to monitor their health and send data to health providers, the survey results show that only 18% of those companies are fully applying the use of such new technologies and syncing patient data with medical workflows and Electronic Health Records (EHRs). According to the survey, only 12% of device companies believed that they were efficiently integrating this data with their R&D systems to drive innovation.

**2014 PwC Global CEO Survey**

89% of the drug and device CEOs surveyed by PwC were found to view technological advances as the number one transformative global trend that would act most upon their business over the following five years (see Figure 2). Despite this, it was also found that many traditional companies have not set a similar pace internally, with approximately 75% of industry executives citing difficulties with quickly understanding and adapting to new information technologies as their biggest barrier.
Figure 20. Digital technologies of highest strategic importance.

SOURCE: Data from PwC Global CEO Survey, 2014.

2014 PwC Digital IQ Survey

This survey highlights that the most frequent digital investments among drug and device companies in 2013 were made in the areas of data mining and analysis technologies. While 82% of the surveyed executives were in agreement as to the competitive edge that big data would give their organization, approximately 66% acknowledged the challenging trajectory of moving their companies from data to insight. The survey findings further predict that the major firms are likely to construct high-tech capabilities allowing their teams meaningfully to engage with data sets and subsequently generate actionable insights. The findings also indicate that around 33% of drug and device companies will make bigger investments in developing data visualization technology in 2014.

Simulation and scenario modelling is another major area in which drug and device companies invested in 2014. This is because these techniques, leading to proofs of
concept, will ultimately help to prove the value of these companies’ products and services, strongly endorse leadership, develop foundational components, test the company’s ability to scale, and create contingency plans for risk. Companies can also apply simulation technology to test and design business models based on digital health tools in order to deliver a better consumer experience, and consistently capacity build so as to identify and scale promising concepts.

Another key finding of the Digital IQ Survey is that drug and device companies are aiming to expand the reach of their mobile application technology. In 2012, drug and device executives’ recorded top digital technology investment area was mobile apps and technologies for employees. Apps and technologies designed for consumer use were among executives’ top five mobile technology priorities. In 2014, the companies surveyed expect the biggest market to be in the mobile area, with over 60% of firms are investing more in consumer mobility, cloud, and sensing technologies.

Drug and device executives named social media targeted externally, at consumers, as being of utmost strategic value over the following three to five years. Interestingly, while most drug and device companies’ mobile strategies have focused on consumer education, some firms may be missing opportunities to apply mobile technology in ways that yield greater returns. For example, while 36% of drug and device companies recorded their primary use of mobile technology to be to inform and educate customers, only 6% said they applied it to capture and co-create new product and service ideas with contributors outside of the organization (see Figure 21).
Figure 21. Drug and device companies’ use of mobile technology
SOURCE: Data from PwC Digital IQ Survey, 2014.

2014 PwC Global Data and Analytics (Big Decisions) Survey

Drug and device companies have traditionally used data to generate a competitive advantage or other intrinsic company value. As the 2014 Big Decisions Survey indicates, nearly 33% of drug and device executives believed their senior leaders to lack the expertise needed to take full advantage of data. In response to this, firms are beginning to construct a more data-driven, broader picture of patients and customers. Of all surveyed executives who said their company had altered its approach to major decision making in response to the findings from big data, or enhanced data analysis over the recent years, 55% reported applying new, more in-depth data sets from external sources, compared to 45% of executives from other industries.

A challenge found in the survey results was companies’ difficulty in assessing
data quality. In addition, just over 33% of drug and device companies reported the timeliness with which they receive their data to be “poor,” compared to 23% of companies across other industries.

**Conclusion**

The key takeaway from the reference survey evaluation is the onus on delivering on consumer expectations for convenience and value in the new health economy. In order to do this, healthcare companies need the right mix of IT/digital tools to accelerate innovation in R&D and across the business as new entrants to the industry begin to erode their market position. Industry leaders are investing in emerging technology platforms, social, mobile and cloud technologies, R&D analytics, new skill sets, and data-sharing relationships to help them achieve breakthrough innovation faster.

c. **Primary Data**

   i. **Government Case study**

   Despite the success of the SBIR/STTR program, recent interpretations of conflicts of interest, as well as changes in what constitutes a significant financial interest (SFI), have threatened to undermine it. Historically, phase I SBIR/STTRs have been exempt from SFI, which allowed academic inventors being able to receive funding for their efforts on a phase I SBIR/STTR proposal. Recently, this exemption was almost lifted by the NIH due to lack of public comment or input from the research community on the proposed new SFI policy. This is, in part, due to the fact that notifications to solicit public comment are published in places such as the Federal Register, which are not often perused by faculty at institutions of higher education. However, as found through the
current case study research, stakeholders from this group feel strongly that the SFI exemption for phase I SBIR/STTRs should be maintained, for several reasons. The first is that the U.S. has seen a significant downsizing of research and development at large pharmaceutical companies, meaning that innovation in the form of early stage product development is increasingly emerging from the country’s universities. Moreover, innovations relating to orphan diseases (diseases that affect < 200,000 patients per year) are particularly more likely to arise from institutions of higher education. For these innovations to be translated into therapies, commercialization has to occur; in fact, “translational research” and commercialization arguably have to go hand in hand. Thus, although a small business entity may be capable of commercialization, the ultimate success of the technology may be greatly enhanced by having the (academic) inventor of the technology heavily engaged in its early development. For example, if a doctor discovers a way of producing a protein for patients with a genetic deficiency of that particular protein, she can produce a correctly folded recombinant protein on a small non-commercial scale, achieving the required potency using an assay that was developed in her lab. If a small company then expresses interest in working with her to produce this protein on a commercial scale for patients under an SBIR/STTR, it would, of course, be advantageous for the company to have the doctor formally engaged with the company during this transition. This is the rationale for the Phase I exemption.

Despite this rationale, many university conflict of interest policies seem confused about it. For example, the University of North Carolina’s (UNC) revised COI policy states that federally sponsored SBIR or STTR research projects raise “special concerns”,

108
and only allows faculty participation if “compelling evidence” can be provided. The UNC policy also does not specifically highlight the differences between a phase I application, where NIH allows the academic inventor to participate, and a phase II application where NIH does not. Other universities’ policies do not make provisions for the paid efforts of university faculty or allow Co-PI status regardless of inventor status. These policies can make a phase I application significantly less competitive and, moreover, appear to be counter-productive to the mission of NIH and the SBIR/STTR program.

ii. Academic interview results

Building on the findings from the document review relating to metrics and measures used for the value assessment of research, key motifs were drawn out in order to conduct qualitative, in-depth interviews with academic technology transfer stakeholders to further understand the nuances around these. This section presents the findings from these interviews, structured by the major themes that emerged. Please see the methodology section for participant details.

Innovation creation

The most prominent motif that emerged from the interviews was that of the consideration, and in some cases outright use, of various elements of innovation creation as a way of assessing research impact. These elements chiefly comprised the development of intellectual property (IP) and patents (applied for and granted), program revenue, license agreements, and invention disclosures.

The most frequently mentioned of these, among nearly a third of respondents, were IP and patents. The following comments demonstrate the importance attached to these as measures of research impact: “the most obvious measures, which have been used traditionally and those are patents”; “patents, because those are easy to measure and evaluate”; and “it makes sense as a proxy and it’s definitely one of the things that I would look at - how many patents are coming out of a given grant.”

However, despite these assertions, IP and patents applied for/granted were not seen to be without their challenges in terms of being reliable and valid impact metrics. One interviewee, for example, raised concern about the potential misuse of such a metric purely for the purpose of obtaining further funding as opposed to fueling innovation per se: “Sometimes I actually think it incentivizes people to spend money on patents, when maybe that is not the highest and best use for the money that they have, and it would be better to put it back into basic research or to use it in other ways… I have seen that subtle pressure where the investigators might want us to patent in an area, not because they think there is great use for the patent, but because they want to make sure that their funding agency knows that they are doing some interesting work.”

Another challenge raised here was with regard to the technicalities of moving from patents applied for to those granted, and the time lag between the latter and the final, real product emerging: “some universities count actual patents granted, but increasingly there is uncertainty with the patents office (USPTO) whether a patent will actually be granted following an application, that more universities measure total applications instead of granted patents, they should stop doing this. Also there is a lag between patent applications and actual patents granted, which universities have no
control over, causing a lot of universities to move away from that particular measure.” Echoing this, another respondent referred to the industry side, i.e. the body or business licensing the patent, in terms of potential reluctance to do so owing to time and other constraints: “unless the discovery is very close to the market and if it is right off the bench, it is very difficult to find a licensee who is willing to take a chance on this… they don’t know what the market value is, and there is also no clarity on the market value on the university side. So a lot of discoveries end up getting not patented.”

While risk relating to time and potentially misused motivations for applying for patents (i.e. for funding purposes) are real concerns, IP and patents were nonetheless seen to be one of the more uniform and reliable ways of measuring research impact, particularly if carefully managed and given the right opportunities. As two respondents commented: “we’ve got world class preeminent researchers and we feel that if we’re providing good services and we’re managing their intellectual property effectively then good things will happen,” and: “you don’t know which ones will ever turn out to be big, so we’re just trying to plant as many seeds as possible and give those seeds a chance to grow.”

Program revenue and grants were also seen as a prominent metric by a smaller proportion of respondents, often also in relation to patents and license agreements, as the following quotes illustrate: “we certainly have a number of metrics that focus specifically on revenue; how much money we’re making from our patent in relation to research operations”; “we look at research investments and we try to categorize that for example as SBIR or STTR type of funding, foundation funding, or traditional research funding”.

However, this category of metric, too, was criticized for various reasons. The first
was that revenue and institutional effort often do not relate. As one respondent made clear: “if let’s say I have the smartest general council in the world, our technology transfer office is the best trained, working hard, making the best decisions on our patents and doing the best job in licensing - we still may not be making much money from our licenses if factors out of our control don’t result in blockbuster products from those licenses. For the same account our office might do a mediocre job and make tons of money based on one or two technologies that by the same factors of chance could give us the lion share of all our license revenues.” License revenue was also seen to be a challenging metric given its potential to conflict with university policy; as one respondent pointed out: “the constant drive towards generating revenue licensing is all based on the budget model of the university. If it’s the university’s prerogative to make money, it makes it very hard for a tech transfer office to be flexible and execute more licenses at a lower monetary value to promote risk-sharing.”

Interestingly, these critiques, often linked to those using patent counts as metrics, were often related back to the fundamental integrity of the institution and the need for it to, above all else, stay true to its mission. For example, one respondent was very clear about license revenue needing to be secondary to the university’s ethos of public service: “we license intellectual property, but the university is a big diverse place doing all sorts of basic research for all sorts of reasons beyond licensing that good public research universities do research for. Producing patentable intellectual property that makes lots of money is just one factor. I think it is a good thing for the university to do, but it certainly shouldn’t be the only thing it should be doing.” Similarly, others commented that: “you can have mercantile motivations without needing to extract every last dollar for the
university, there has to be room to make a public good distinction.” and “the tech transfer office is not trying to maximize its profit, however that is defined; you have to keep broader mission of the institution in mind.”

The number of executed license agreements were the next most mentioned metric, often conflated with patents: “intellectual property patents, licensing and research agreements, material transfer agreements, confidentiality agreements, all the things that we do,” “the number of licenses, and the revenue that is generated through those licenses”.

Similar concerns were raised as with those regarding patenting; for example, the latter interviewee went on to say that looking at the number of license agreements can, at best, be seen as a ‘proxy measure’ rather than a reliable metric, especially given the time lag issue: “I think what all tech transfer offices struggle with is there is this big lag time between the time to license or patent a technology after the time you bring research money in. Most technologies don’t make any money; many make very little money and only a very few make lots and lots of money. So even if a tech transfer office or research program is doing all the right things and doing all the right patenting and developing interesting intellectual property, it could still never make any money. Or it is possible lightning may strike on a project that wasn’t handled as well but happens to come up with a patent that turns out to be very valuable.” Another respondent dealing with a similar concern indicated that their office dealt with this unpredictability by building in various contingencies: “we are sowing lots of seeds today, so that we may have a large number of licenses of which we can’t really predict how many are going to mature. We also have all sorts of contingencies built into the license agreements that allow us to claw back the
technology if we don’t think it’s being developed within a certain timeframe, or within the levels that we think it should be developed. So I do think that is important to think about it in terms of the whole life cycle of the patient, and the life cycle of the technology too.” Both of these insights suggest that the number license agreements and patents and their associated revenue alone are not enough to comprise distinct metrics - a holistic view of the ‘life cycle’ of research and its impact is ideally what is needed.

A minority of respondents viewed invention disclosures as the least contentious way of measuring impact; for example: “I wouldn’t worry about patenting, and I wouldn’t worry about patent granted - I would look at disclosures. What is the rate of disclosures, and whether that rate of disclosure is changing in a positive direction over time within the university”; “the number of disclosures we get… can be helpful to figure out what resources we need. It can also tell you whether more people are becoming interested and use them to see if you can detect something that might be useful to you in operating the office”; and “you want to see how many invention disclosures you have to monitor if there is a dramatic drop off so that you can investigate why that is. There might be good reasons, but if it’s because university researchers are thinking your office is a black hole’ or whatever, then that’s a good indicator that you are not meeting the needs of your researchers.” From these perspectives, it is evident that considering invention disclosures is not only a good way of tracking potential impact, but also of helping universities to plan and manage their resources.

**Knowledge acceleration and incubation**

While less frequently mentioned than innovation creation measures, the dollar value of sponsored research agreements or services provided to industry, and start-up
company incubation and acceleration program success were also viewed by respondents as valid indicators of research impact. Respondents’ comments reflecting this included: “we use that basis of the dollars’ worth of research and surmise from that,” “every dollar that goes into research has some societal impact,” and “[university] has now a 20+ year robust survey that’s issued annually and it’s always written up in [newspaper] and the only thing they ever talk about is the number of dollars revenue generated because that’s a nice easy soundbite.” The latter evokes a sense of skepticism in association with this metric, which a couple of others also expressed, largely owing to what was perceived as superficial, politically driven value rather than necessarily generating real, long term impact. As one respondent asserted: “frankly, in some way they are bragging points and you all know at the moment that legislators are looking for anywhere that they can preen, cut or slash any expenses. So we have used these numbers, these reports to describe the value that we add and every dollar that through legislation flows into our activities brings in some multiple of that number. Of course, hardcore metric folks would grimace if you look at some of the imaginations that people use here. But you know, one of the simple ones is we had an economic impact study performed a little over a year ago, which put us at about $5 billion economic impact. So very simplistic naïve approach there that the state gave us $230 million last year, and look what we did with it. It turned into $5 billion of impact. And of course everyone knows that’s not how it works.”

Incubation and acceleration program success were seen as less controversial indicators, which were often linked with real market and community outcomes: “universities are trying to put programs in place like accelerators where there is an interesting discovery, and there appears to be an identified market for that they can
accommodate”; and “the incubator shows how engaged are you in investing in the community, and how successful have you been in bringing in outside investment dollars to support the commercial activity.” However, remarks relating to these were in the minority, suggesting that this is an indicator that could be paid closer attention to in the future given its potential for both market and community engagement.

Collaborations

The extent to which universities and their faculty and technology transfer officers engage with external collaborators was strongly seen as another way of gauging the outcomes of their research, although perhaps less so the concrete impact. Key collaborations included industry relationships, especially those resulting in license revenue.

Industry relationships were seen as being valuable in advancing often basic university science towards practical applications through industry development resources, as well as the importance of industry expertise in business management and marketing as one respondent highlighted: “It is [a] pretty rare circumstance where an academic inventor is going to be the industry founder who leads the company through commercialization and then market launch. That’s a pretty unique person, particularly if they have not done that before and they don’t have a business underpinning within their background at some point of their life… it is often important (1) to find the right commercial leader, and (2) finding a leader that gels well with your academic inventor.”

More specific industry collaborations were also mentioned, notably clinical trials: “from my university, clinical trial activity is a huge component, where companies need capacity and clinical expertise, so we have access to a patient population that is a great
interest to a lot of pharma companies for their clinical trials.” This feeds into another frequently mentioned aspect of industry collaborations - relating to academia and industry’s partnerships as a way of service to the community. Such collaborations often appeared to inject a sense of purpose into the other types of collaborations and, again, reiterate the sense of mission of each institution. In discussing their connections with industry, respondents who gave the following quotes illustrate this: “[we] see the commercialization of technology as a service to the broader community. It is a way to disseminate knowledge, as knowledge is the way to create impact for the good of society or for the reasons of discovery”; and “we actually have a mission statement behind that… ‘Encourage, educate, and enable the community to achieve its commercial potential’.”

One new partnership model that came up is that of academic-industry drug discovery and development centers. As one respondent described: “Now in some instances, in pharma for example… universities have now become drug developing centers… and this is a way of engaging real partnerships, where you have pharma that is working in some therapeutic area, like psychiatric drugs for example, and putting their scientists together with university scientists in common labs to actually do discovery. This type of academic-industry co-discovery is less than a year old and that is a new model of creating partnerships.”

It should be noted that, alongside external collaborations, importance was also given to nurturing key internal partnerships and a sense of community around a new technology being developed. One interviewee strongly conveyed this: “So how do you decide to develop the technology? You walk the halls. Even although it’s about our technology, ultimately it is about our people, and from a technological point of view most
of these folks are… students but often it’s Ph.D.’s, post doc, professors and the first metric is that they are usually thought leaders in their field of research.” Likewise, another person asserted that: “if you don’t have a cooperative faculty, the inventors, then you’re not going to be successful at all. So you want to have them wanting to work with you because at some level down in the trenches their continued involvement is critical to moving forward in forming a startup or initiating a relationship with another industry partner.”

While one person mentioned the use of APLU metrics for measuring the impact of collaborations, other implied that measuring this overall - particularly with regard to models of partnership that are service and community oriented - is difficult to do given the lack of clear cause and effect indicators in this instance. For that reason, the majority of respondents who commented on this aspect emphasized that metrics for measuring collaborations should take into account tangible elements such as the revenue garnered, as the following convey: “we absolutely worry about the quality of the partnerships… It’s a negotiated agreement, and we ask for diligence in terms of their development of the technology. We demand that they retain rights so that we and other non-profits can practice technology, so there are all sorts of negotiated partnerships,” and “if you created a metric that says partnerships work, then you would expect the universities to focus the attention on creating partnerships, and that’s not what’s really been happening. What they are looking for are partnerships that are actually willing to pay for the IP. So in some ways partnerships are thought as a way to monetize the technology.” The latter suggests that partnerships can be considered a bridge towards concrete research outcomes rather than a gauge toward impact by itself.
Cultural change

Perceptions of the need for metrics, and how they should be constructed and applied, were seen throughout the interviews to be subject to more important cultural aspects relating to each of the respective institutions. These included increased awareness and respect for entrepreneurial themes on campus and in curricula, varying attitudes towards metrics themselves, and recognition of the importance of the culture and people.

The notion of entrepreneurial outcomes as indicators of research impact were seen as increasingly valid and present both among the student body and faculty: “there are now more courses and programs related to this [entrepreneurship]. And at the end of the day, that is almost as important as anything else that I mentioned before because it teaches the students how to think like entrepreneurs, as well as provide faculty researchers a sense of what the commercial orientation is like, what it’s like to formulate a strategy, to commercialize an invention, so that’s important as well. We don’t systematically measure that, but perhaps we should because I think that is a true reflection on how important commercialization is on campus.” In one case, this focus was directly linked with tenure: “promotion in the tenure process is… now being valued explicitly through entrepreneurial engagement… When I came to [university], no one was focused on this activity at all… Part of this is opportunistic because the institution knows it can generate more resources from the state or from alumni if they are entrepreneurially engaged. Once it becomes a consideration for promotion and tenure however, it is going to be even more embedded in the culture.” This also raises a potential danger of tenure being associated with entrepreneurial metrics related to research impact; namely, the ‘opportunism’ of such metrics being used for personal and monetary gain rather than the development of knowledge per se.
With regard to the broader culture around metrics, in particular the attitudes displayed by the various stakeholders, it was pointed out that stakeholders themselves are key to constructing and implementing metrics with integrity and consistency. As one interviewee observed, “the communications department… is in lock-step with us in trying to tell a story… trying to make stakeholders and legislators aware that their investment is being well managed and creating impacts that can relate to the community.”

**Entrepreneurial focus**

Entrepreneurship-related markers of research value assessment were broadly mentioned across most interviews, particularly with regard to new equity relationships created, and the amount of start-up activity, including tracking the actual number of start-ups emerging from a particular research project or resulting innovation.

Mentioned by over half of all interviewees, equity relationships were seen as a straightforward and standardized value measure, as conveyed by the following comment: “one of the metrics that I would like to collect simply from a research standpoint is, what is the take-up rate of university discoveries by venture capitalist and firms that back these venture capitalists… if we can find a way to interest the VCs in the university based discoveries, then I think you have a stronger case to make the technology transfer at university and metrics of this type and it is going to be meaningful in some economic sense.” What this also clearly conveys is that an equity-related metric has the potential to create meaningful, real value economic data relating to research impact.

As a prior step to this, nearly all respondents referred to monitoring the number of start-ups created as a good, concrete indicator of research viability. “Universities are now focusing more and more on the entrepreneurial dimension of technology transfer. So that
means calculating the number of start-ups that are created,” “one place you look at is
startup companies and because startups are fun and easier to measure, we over emphasize
startups,” and “it’s the entrepreneurial dimension of tech transfer and commercialization,
and that really needs to be highlighted. That would be the top one,” were typical
observations here. As part of this, some respondents specified that it was important not
only to consider innovation emerging from technology licensing, but also as a result from
research, education and training, suggested by the following: “I would look at the rate of
new business starts, stemming from university discoveries, not just business starts but the
student start-up businesses and those professors start all the time, and not necessarily
from university funded research.” This would then serve to capture the broader economic
value of the university’s collective resources and networks, something that will be further
discussed in the following section.

Interestingly, start-up survival was also deemed a key follow-on metric. As one
interviewee emphasized: “you need to go beyond just measuring quantity of start-ups,
you have to calculate some measures of the economic outcomes associated with those
start-ups. Whether they are surviving, or whether they are growing, or engaged in
additional research or additional commercialization.” Similarly, another made clear,
“measuring the quality of a start-up would be measuring the success of the start-up,
which could be measured by additional patenting, licensing revenue, revenue growth,
employment, or job creation.”

Other factors that the respondents considered important within the entrepreneurial
focus category included job creation and, in particular, students’ own trajectories once
they left the university. As several people recounted: “for example, we look at
employment, and graduates from these programs. We look at how many students are engaged with companies.” Another key aspect was whether or not start-ups’ products/services actually work, i.e. the final viability of the research innovation: “coming from the tech transfer world, I do like the idea of trying to come up with numbers that would look at the products developed from my work.”

Several of these metrics inevitably overlap with the wider impact that institutions’ research activities can have on the region in which they are based, and more widely in economic growth, as the following section discusses.

**Economic development**

The key motifs here included developing the local and regional workforce and job creation. It is worth noting that these themes, in the context of economic development, were mentioned with far lower frequency than the previous ones discussed, as respondents tended to conflate these aspects particularly with start-up creation. While one interviewee specifically cited “developing the local and regional workforce” as a measure that could be considered, another presented a more nuanced view of how this could be actioned: “When I first started working in this office the emphasis was on patenting and licensing and I think it has changed over time, and it is really focused more on the entrepreneurial dimensions of technology transfer now. This is consistent with the arguments that universities are making, which I think is a legitimate one. You know, they contribute to the local and regional economy, so they are focused on measures that relate to economic outcomes from commercialization.” Here, again, is evidence of the importance of employing a holistic approach to measuring research impact overall, as it is inevitably difficult to separate universities’ contribution to entrepreneurship from
regional economic development.

**Qualitative outcomes**

Nearly all respondents were in agreement as to the need for implementing new measurement categories for research value metrics, particularly those taking into account qualitative outcomes. These could include case studies of start-ups successfully created and the ‘story’ of the individual entrepreneurs or successful product (especially if the latter also holds social value), vignettes of stakeholders and stages through the process from research inception - development, and interview-based stakeholder surveys.

Specifically, proposed new measurement categories included qualitatively understanding “the internal organizational processes that either hinder or help disclosure… The other thing that universities are always grappling with is that they are trying to align patent and license incentives, so the people actually doing the evaluations and making the decisions on whether or not to patent are in sync the people who actually try to go out and do the deals to get those things licensed.” The implication here is that more engagement with internal stakeholders would enable a deep - rather than broad - consideration of the factors at the root of research value creation. One suggested way of putting these into practice was enabling “crosstalk between various groups who were involved in generating metric programs for research valuation”; this interviewee went on to explain how “several universities did a small pilot scale run about a year ago where they brought in stakeholders who touched on each one of these three areas. The results were collected and reviewed and impressions were refined a little bit.” Again, the emphasis here is on telling the story of the people and the innovation behind the ultimate product/service/impact. Several respondents asserted that this element was crucial,
perhaps even more so than numbers alone: “it is very difficult to systematically measure entrepreneurial outcomes from technology transfer. [Universities] for many years now have collected the number of start-ups that each university is generating each year and that is one of the metrics that they use. But it’s important to realize that that doesn’t tell the whole story about what the outcomes are”; and, as another succinctly put it, “the recognition came up that while we really wanted to be as analytical and quantitative as possible, it became very clear that this whole exercise begs a narrative attached to any numbers that we are able to collect. You have to be able to explain why it matters for your region and your locality. You know, nobody just wants to tell stories and everybody wants it to be fact and metrics based in a very rigid and robust way, but we recognize that you have to have a story alongside it or it loses some of the impact.” These comments clearly point to the need for narrative-based metrics focusing on the less tangible value, alongside quantitative measures.

**University mission and accountability to stakeholders**

Nearly all respondents highlighted that, regardless of the research impact demonstrated and the metrics used, these elements ultimately needed to be aligned with the mission of the research-producing institution. This was the case, firstly, owing to the fact that “tech transfer has always been part of the mission” of several of these institutions, as one interviewee pointed out, going on to say that “the tech transfer office is not trying to maximize its profit, however that is defined – there is a broader mission than that.” This strongly conveys that monetary-based metrics of research impact simply do not tell the whole story - institutional integrity is another key factor. Another respondent reiterated this: “we invest a lot of time, energy, and capital in our [signature
innovation]. Not only in patenting it but in creating a separated non-profit to develop [the technology], not because we could make money on it but because there is a gap in the funding resources for [basic] research because it was an important area of science to develop.”

In discussing this and how metrics could best be applied, several respondents candidly stated that there was no one right way of systematically measuring research impact, as the following quotes illustrate: “personally, I don’t think there is a best model. I think a lot of it is driven by the mission of the University, and right now there is a big disconnect between those of us that are in the tech transfer community know what the average value of a patent is, zero, and what the university administrations think they can make from these things,” and “it’s very experimental and everybody is trying little bits of something different, it really comes back to the commitment of the leadership of the University – often the president’s office.” Thus a one-size-fits all approach or framework for gauging impact was not necessarily seen to be the most suitable approach. On the other hand, it was also acknowledged that “yes, the goal is to benefit society, but the way to achieve that goal is through the mercantile motive,” which then does necessitate concrete, systematic measurement. The lack of consensus between these replies suggest that a tailored approach layered over a set of fundamental principles may be useful…

Another key factor to consider here was that of stakeholders - i.e., who the research impact was being measured for, and why. For example, one interviewee stated that “we measure those things because they’re relevant to our community,” while several others clearly signaled public sector officials (i.e. states and governors) as the dominant stakeholders, with clear awareness that metrics in this context could be political
motivated: “I think the legislators are interested in this. Our governor is very interested and he mentioned it exclusively in his State address… in our case and I think in several other states the politicians are very important stakeholders.” Alternatively, there was also the view that metrics should most reasonably respond to the requirements of those funding the research in the first place: “I think that metrics should be focused on those dimensions that the people who fund the technology are most interested in.” These comments indicate the importance of being sensitive to the audience of metrics as they are applied, with care taken to ensure that the metrics themselves are used in a consistent manner regardless of political considerations.

Interestingly, the stakeholders most often deemed to be the key ones who both need and in themselves demonstrate evidence of research value, were students and alumni. Going back to university mission statements, several stakeholders felt that tracking students and what they did with the knowledge they acquired was a major indicator of value outcomes: “I think the vast majority of technology transfer is through the education and training of students that go off and work in companies and use the training and the knowledge that they’ve received at the university to make the world a better place. That I think significantly outweighs tech transfer in terms of licensing patents.” while another stated that: “we’re looking at how connected our students are to potential employers and how these employers in industry are able to get value out of our (former) students work product.”
Challenges of designing and applying metrics

Nearly all respondents acknowledged the pressure that currently exists, and is seen to be growing, on universities and other research institutions to provide evidence of their research value. As one interviewee replied when asked about the importance of having a more comprehensive metrics framework, “I think this is important because there is a lot of pressure on funding agencies to document the economic outcomes of the technologies that they support.” Another also commented that the presence of customized, institutional metrics was already in place: “every university has a strategic plan and they do attempt, very crudely, to measure the effectiveness of that strategic plan, so there are universal metrics in place.”

However, a commonality was the understanding of high variability in terms of the impact of individual research projects, and the need to tailor metrics both to the outcomes being measured, the environment, size of the university, stakeholders, and other factors. This, in turn, raised several challenges. One respondent aptly summarized this collective challenge: “if you are going to collect metrics then you have to collect the metrics along the entire value chain, so not just things like patenting. I mean you ought to trace back the relationship between the patenting behavior and the actual outcomes… I would think of these as measures of intermediate processes that lead to some ultimate goal. Now what that goal is depends on your audience… My fear right now is that a lot of the metrics that have been collected are collected in isolation from an understanding of the actual processes around them.” Again, therefore, there emerges the importance of applying a holistic approach, one which tells the story of the innovation as much as its eventual outcome.

Others, too, emphasized the need for customized measures, especially given the
unique characteristics of each institution. One respondent, for example, made the case that it would be “unfair to compare [university a] in terms of its startup activity to [university b] even if they have comparable federal research budgets because they’re in a different economic climate focused on different industries, etc. So that’s where I really struggle with the metrics.” Interestingly, alongside this emphasis on tailored metrics was a certain tension around having metrics that were too individualized: “I just don’t think there is a right answer, I think with each of those metrics you have a sort of understanding that it’s not a perfect metric for how all well an operation is doing…” Maybe these metrics are pretty self-defined and kind of fluid.” Thus, while portrayed as necessary to an extent, the usefulness of having such ‘fluid’ metrics as the defining way of undertaking research impact analysis may be seen as debatable within an overarching policy framework…

**Institutional variations**
Notwithstanding the small nature of the sample, certain noteworthy differences were discerned between institutions with particular characteristics (please refer to the methods section for an overview of these variables). Firstly, it was found that private institutions were much more likely to take cultural and attitudinal changes/effects with regard to metrics into account, and understand the need for change in terms of valuing and applying metrics. It can also be noted that equity relationships as a metric were only present with private institutions. Conversely, public institutions are more likely to receive state funding and so would be more focused on framework research towards knowledge creation or economic development on a regional scale rather than considering specific, community stakeholder-led impacts. This was compounded by the finding that public
institutions were more than twice as likely to factor economic development into their research impact/metrics.

Another difference that emerged was that institutions with relatively smaller research and license revenues were most likely to be heavily focused on industry relationships and collaborations.

Institutions with a medical center were also much more likely to be concerned about patents concerned about using patents and revenue as impact metrics.

### iii. Industry interview results

Using the aforementioned key themes extracted from the document review, qualitative interview topics were constructed and applied to key industry stakeholders (as detailed in the methods section). This section presents the findings from these interviews, structured by the major themes that emerged, and in the order of frequency with which they were mentioned by respondents.

**Emerging technology platforms**

In discussing the ways in which new technology platforms were emerging in their fields and within the scope of their businesses, respondents largely referred to alignment and engagement with external stakeholders (both in the same sector and others) as key, alongside product and service innovation.

Stakeholder engagement was a major theme for all but one of the respondents, with this often seen as a cost-efficient way of pooling knowledge and resources. As one respondent observed, many companies are participating in industry initiatives rather than building their own collaboration platforms, bringing together multiple industry
stakeholders to share data and invest in promising entrepreneurs. Sometimes, this engagement was found to occur at community stakeholder level as well as with other business/private interests; for example, one company collaborates with internal and external stakeholders to crowdfund innovative ideas for tackling a particular unsafe health practice. The company tests hypotheses on communities to engage, digital and physical platforms to use, and how all participants will benefit. This has ultimately helped to lower infection rates for its hospital partners, thus concretely demonstrating the impact and value of community engagement in developing this innovation.

Finally, stakeholder engagement was seen to be important in aligning capabilities across the different entities involved. One respondent, of example, made the point that, before investing heavily in new services they think will work for providers, drug and device companies should understand how far along providers are in adopting innovative methods of care delivery, stating that: “if we’re disjointed from a service perspective, we’re going to be disjointed from a technology perspective, too.”

Exploring emerging technology platforms also revealed that key industry players were more likely to be innovating on their service models rather than their products, often in order to better harness the products themselves. For example, one large medical device company has moved from simply supplying medical devices to providing a variety of medical services related to their devices by 1) expanding its role in patient care and treatment, and 2) by providing additional services to hospitals, ultimately making it a major player in a new market. Better serviced technology can also help in product development by smoothing the R&D process, as one respondent made clear: “formulation is a bottleneck in the R&D process for many pharmaceutical companies. New technology
can help us predict the best formulations in three to four months versus 18 months.”

**R&D analytics**

The challenges of dealing with big data, and data sharing relationships, emerged as key themes when considering the role of R&D analytics. Firstly, it was widely agreed that an analytics system was necessary for the purpose of obtaining and mining data relating to customers, the wider market, and the success of a particular technological innovation. As one respondent stated, “to get the most out of the platforms, you have to add an analytics engine.” This was also seen as lending greater credibility to certain providers, in that comprehensive analytics are evidence of “real-world effectiveness,” particularly relevant to the medtech industry as, in the words of one interviewee, “pharma wants to be able to show evidence that they are the better choice from a formulary standpoint.”

However, half of all industry respondents noted challenges with using analytics and big data as such. One was the issue of how to manage the data and make it work in the most efficient way for the company - one respondent raised the question of whether or not it is better to “go to one data model, or do you integrate and build correlations between the individual data marts?” Another challenge lies in integrating the data once it is gathered. For example, another interviewee discussed how most hospitals have a data integration problem, where IT departments focus on data management, not on information management: “IT departments are strong at managing vendors, but are no masters of information… there is a need for information specialists.” In this case, a central repository approach could help, whereby the hospital takes a content agnostic view of the information gathered.
Finally, there is the challenge of the quality and consistency of the data itself. For instance, companies such as Optum are capturing new but often incomplete data from sources such as EMRs, cohort studies, and registries. They are starting to derive what might be considered weak signals from them to inform decision making and guide investments in complete data sets through randomized clinical trials. To aid the process, enlisting patient participation may help to form a more complete picture, as patients may be willing to share their health data if they believe it could benefit them in the long run.

Alongside the latter and other solutions posited, data sharing relationships were seen as another way of maximizing on data. Through Project Data Sphere, for example, competitor drug makers such as AstraZeneca, Pfizer and Sanofi work with research organizations to collect and share anonymized patient-level data from oncology studies. In cases like these, data sharing can, in itself, be seen as the innovation.

**Social, mobile and cloud technologies**

The most prominent use of these technologies among the interviewed medtech sample was for the purpose of business development. This was followed by use for data sharing and co-creation purposes, problem solving and product servicing, and for R&D.

Half of all respondents notes using these technologies for business purposes, which extended to developing it for retail, sales and marketing, enabling a social presence with consumers, and increasing the reach and frequency of their products among providers. Social networks were most frequently harnessed here; one of the companies, for example, operates active blogs and live chatting for its patients, advocating that “companies should also scan social media for information about adverse events related to their products,” particularly in light of a recent study which showed that Twitter had three
times more adverse event reports for 23 commonly used prescription medications than the FDA did during the same time period. This conveys the growing importance and seriousness attached to social network technologies, and their potential to be both a source of data and market impact.

With regard to data sharing and co-creation/improvement of products and services by way of user feedback, mobile and digital platforms alongside social networks were seen to be key. One company was able to generate very detailed user profiles based solely on individual likes/dislikes on Facebook, while another uses Salesforce.com to enable clinicians to exchange data and observations via the platform. In particular, it was noted that leading companies generally develop deeper, more direct mobile-based relationships with patients, not just with their internal employees or physician customers. Some drug and device companies are also implementing consumer mobile apps that enable patients to better manage their care, highlighting the increasing importance of mobile technology strategies to this sector.

Increasingly sophisticated digital packages are also being used to troubleshoot and innovate on existing products, such as software used by one respondent’s firm that brings together critical information that diabetes patients and their physicians can both view, preparing reports that reveal patterns to help inform therapy adjustments. Another company has used such software to improve their customer journey by considering all stakeholders in the ecosystem of a particular illness and creating a digital app for patient support upon initial diagnosis, which can then conned patients to resources where they live.

Finally, there was evidence of mobile and cloud platforms being used for R&D
functions, including clinical trial management, building the initial infrastructure for a new product/service, and collecting information from existing devices to triangulate understandings of how best to innovate. One company was particularly proactive and expansive in this arena, using social platforms and collaborative technologies in R&D to create an “electronic idea competition,” where global research and engineering teams can post problems that are then shared internally across the organization to solicit solutions, only being shared externally if no internal solutions are found. This and the other diverse means of using social, mobile and cloud technologies stake these out as being at the forefront of medtech companies’ innovation streams and, indeed, as rich with potential to generate data with regard to concrete technology outcomes and outputs.

**New skill-sets**

Human capital considerations, while only mentioned by a minority of respondents, can nonetheless be seen as important with regard to the capacity (and lack of this) to action the innovations and gather data as to their product and market effectiveness. As one respondent made clear, the three key competencies needed in this are business, statistics, and technology; they made the point that, while “industry has a good mix of business/technology people, but when you add in statistics – it’s hard to find it all in one person.” Likewise, another acknowledged that while “existing pockets of capacity exist” in terms of technological innovation in their company, this was “nowhere near the envisioned need.” The evidence here points to a skills and also capacity gap in terms of engaging with digital tools and making it workable both internally and for key stakeholders such as patients. This is obviously a key point to consider when relating to impact metrics as without the skills to measure product success and real life outcomes
such as improved health, this part of the process will encounter significant time and resource constraints.

**Integration**

This theme refers to the ways in which the industry players interviewed here are connecting their core business systems with new technologies. A common motif among half of all respondents, this primarily covered “connecting the old with the new” in terms of essential systems such as inventory management connecting with new platforms such as mobile apps, and using technology as an enabler for improved business models - the “Christiansen view of innovation,” as one respondent referred to it.

As a prominent example of connecting core and new technologies across the innovation spectrum, Medtronic recently acquired digital health company Cardiocom, which offers remote monitoring for heart patients “We are now able to reach the 90% of cardiology patients who do not need one of our pacemakers but still have a need for monitoring and managing their disease,” said one of the informants intimately aware of these systems. Medtronic uses cloud platform CareLink to connect its devices and link them to provider EHRs. The system also brings together critical information from insulin pumps and glucose monitors that diabetes patients and their physicians can both view. Finally, the software prepares reports that reveal patterns and trends to help inform therapy adjustments.

Other examples here include one firm’s goal of establishing itself as the world’s leading care company in a particular health field by becoming “a ‘360’ partner of the patient; delivering best-in-class and integrated solutions to diabetic patients … through the integration of new pharmacological targets and innovative approaches and the
seamless connection of diagnostics, treatment and monitoring.” This includes the full range of products and services, including monitoring devices, oral and injectable therapies, mobile applications and patient education. Another example is that of innovating existing care through the integration of new technologies, with one firm that facilitates hospital to home transition, and is aiming to improve its focus on relational care once the patient leaves the hospital. This is likely to entail lo-tech solution focused on care coordination and relationships using home monitoring technology. Both of these examples demonstrate the value of integration and, crucially, the inherent value in measuring its effectiveness in terms of the intended outcomes.

**d. Triangulation themes**

In engaging both with academic and industry stakeholders, the aim of this research was to understand the extent to which, and how, metrics and measures to assess the economic value relationship between them leading to research-driven innovation were being considered and used at both ends. In doing so, certain commonalities emerged across both groups of stakeholders, which will now be discussed.

**i. Consensus metrics**

Building on the aforementioned measures around resources, capacity, technical ability and scientific knowledge/dissemination as inputs were additional outputs and outcomes that could potentially be devised as metrics, as construed by both academic and industry respondents. Perhaps unsurprisingly, the former were less likely to view this in monetary terms than the latter; as one tech transfer officer commented, “if a politician was to look at that and say well we’ve invested and 1000 inventions and only a couple
have really brought back the revenue and it’s not a good return. I guess that is sort of my concern that somebody didn’t know a whole lot about the process and to look at it and say that’s not effective… you shouldn’t really use profit for the tech transfer office.” Conversely, industry stakeholders had much more tangible outputs in mind, such as increases in productivity as demonstrated by asset/labor optimization, measurable increases in capacity through the leveraging of technology, and developing optimized procedure pathway. These difference can arguably be attributed to, as stated above, the identity and, crucially, the primary motivation of each metric stakeholder.

However, stakeholders from both sides were broadly aligned that metrics should take into account both tangible outcomes such as “the effectiveness of entrepreneurship… the advancement of knowledge, and then the best measure of collaboration” (academia), and “real-world effectiveness and commercial success” (industry). Interestingly, the factor that may be seen to unite them - again, conceptualized in specific ways according to the nature of each group - is that of adding intangible value, either by ‘selling’ themselves on that basis (e.g. by improving patients’ quality of life in the case of industry), or by serving the community through the advancement of knowledge and economic development in the case of research institutions.

Finally, it should be noted that input, encompassing factors discussed in the previous section, was seen as vital to include in metrics as any outputs; as one technology transfer interviewee stated: “the metrics are all output and no input… [in] engineering you can’t measure the effectivity of a system by just looking at its output.”

**ii. Innovation determinants**

The most common triangulation theme related to the management theory derived
innovation determinants; that is, certain key elements that both groups of stakeholders saw as fulfilling a catalytic function in driving their common value relationship. These included, most frequently, the importance of understanding the market both in terms of advancing technology capabilities as well as evolving demand patterns, as derived from commentary largely by tech transfer respondents, for example through remarks such as: “we speak to customers and also we often speak to our competitors in getting a sense of what they are doing and to see if their future product roadmaps are going to be competing with where this company is headed.” A few industry respondents also asserted this in their considerations of how best to monetize “data sitting next to the patient” and who would buy it, e.g. providers and pharma.

A specific aspect of these of market considerations was having streamlined path-to-market strategies, considering both the push of technology and the pull of the marketplace. While this issue was raised largely by academia respondents, it arguably relates to both sides as without industry demand for specific discoveries there would be no new products emerging from them. For example, one academia interviewee asserted the importance of both the academia and industry side in forging this pathway: “successful tech transfer is a function of the university pushing and actively marketing and trying to find partners to get the technology into the marketplace, and then market pull where the market acts as agent a lot like investors and companies actively look for opportunities.” Another emphasized the importance of flexible pathways to market according to the nature of the product being developed and the consumer base: “there seems to be a way of technologies being transferred, and from a funding agency standpoint I definitely think you should be agnostic on those questions and not say it has
to be done in an x or y way, but respond to the market, and if that’s what’s going on at the market then good.”

Another commonality was that of being driven by service value and appreciation of relationships. While this factor was mentioned solely by industry respondents, it resonates closely with what several academia interviewees conveyed regarding the importance of universities’ mission and their ethos of public service, as previously discussed. As one industry respondent commented, “hospitals need to leverage technology in the background to enable treating their patients more as human beings, not a set of medical facts in a record… back to the old family doctor values in a new health economy - getting away from the practice of medicine in the isolated building where you get “fixed” when sick.” This arguably also reiterates the importance of research and technology impact metrics taking into account the ‘bigger picture’, i.e. the real story of how impact plays out on the ground, rather than relying on numbers alone.

**iii. Overarching measurement themes**

The major motif here was that of having a talented and interconnected workforce. Tech transfer respondents commenting on this did so largely in the context of the challenges that can occur with limited capacity and high turnover: “the turnover in the transfer office is very high, especially those with PhDs in biochemistry or the sciences, [they] would use the University tech transfer office as a springboard for a training ground then they would get a job say in a venture capital firm in an angel fund or something like that, and that is typically how it goes.”

Covered largely by industry respondents, another consensus theme that emerged was the importance of having accountability and adequate, up to date communication,
Both internally and with your consumer base. These companies are increasingly seeking to align and connect capabilities otherwise “scattered across the organization” in a way that boosts staff capacity to deliver on new technology and, ultimately, provides a better patient experience. As one person commented, “healthcare providers of the future need to be more accountable for health - the patient relationship is important. Companies like Facebook and LinkedIn have nailed it, and know more about patients than hospitals do.” An interconnected workforce was also seen as key to innovating new technology transfer models, in that an academic institution could draw on best practice from other institutions to create a new model, if necessary, to innovate on their processes and input.

Adequate and dependable resources were another key factor, again largely related to human resources, capacity and understanding. As one respondent from academia phrased it, “In addition to the time issues that I have, I really was doing this almost as an independent project… and I realized that a lot of the other campuses that were participating in these activities had a team of three or four people who had in their day job in the description that they needed to be engaged in this, and I just didn’t have those resources behind me here… we don’t have an extension of outreach program of any nature here. So it just became a burden for me to try to do individually… you actually need number crunchers to collect information and I just couldn’t keep doing that.” Likewise, an industry interviewee acknowledged that “the criticality of responsibilities,” was key, as was a “crisp understanding of the challenges on an individual basis…. getting things done and achieving results for patients, we’re not as proud of our results to date.” These concerns suggest that, if metric measurement is to be undertaken in depth and in a systematic manner, the resources must be in place to allow for this from the start, rather
than as an afterthought.

Finally, a broad consensus theme with regard to metrics was that of generating and disseminating world class scientific knowledge, as one respondent from academia described: “how do we create policy intervention that might allow us to categorize all different types of research we might fund? That is then going to go back to an understanding of the fundamental mission of the typical university, which is to create knowledge. Then you create funding and shift that mission from basic knowledge creation to more applied knowledge creation. That is going to be very radical, and it’s going to step on things, like academic freedom and all that. But from a policy maker’s standpoint, I would actually want to think about that and where are the places where they have shown a record of good cutting edge research, and then for those universities that may be more structured to focus on translation research, and let’s figure out a way to incentivize that.” This clearly links universities’ reasons for being with the end metric as much as the actual research impact - indeed, that original mission needs to be an indicator within the metric itself. For their part, industry respondents who broached this theme did so in the context of their own collaboration in industry initiatives to collect and share data which can then help them gauge their market positioning and the effectiveness of the technology they launch. This arguably reiterates the importance of including stakeholders’ identity - in this case, competitive, commercial market players - as an indicator in any type of metric.

iv. Socio-political factors

Underlying the consensus metrics discussed are inevitable mitigating factors, notably those relating to political influences and the differential social/economic
circumstances in which different academic and industry players operate.

These factors emerged, firstly, according to the regional differences between organizations, and concurrent internal sense of fragmentation where organizations were split across different areas. One respondent from academia clearly illustrated this by making the following comparison: “let’s say that my campus, which is a pretty much urban, middle of the city academic medical center, and the things that we do are very different than the things that say [other unit] does, you know… where they are in a very different environment than we are. You could put in many different examples where there are huge contrasts… it seemed to me that the demographics of the participants [involved in a cross-university research project] changed quite substantially over the last 12 to 15 month or so, and that is a lot of smaller non-research universities started an active role… this information is important within their regional stakeholders community to say that we do have an impact… we are doing things to make real differences to our local communities.” This, again, reiterates the importance of considering metrics and measures in the context of the environment in which they occur.

The second variation related to the question of human resources, in the sense that some geographic areas simply contain greater clusters of specific needed talent. As one technology transfer officer explained, institutions are so often “funding both the technical as well as the commercial CEO is that it isn’t their first time over, and the others may be on their second, third or fourth start-up… So there is an implied value that if you run into a academic founder were maybe this is their second or third start-up, there is huge value there. I would say that in the Midwest we are more embryonic than they are out at save the East Coast or West Coast. So it’s nice to have, but if you made it a must to have it’s a
little harder to make things happen here.”

Finally, respondents raised the importance of agility and an enabling political environment with regard to adopting new research, regardless of where it is first developed, in order to then benefit from its impacts in the U.S. The following respondent explained this in depth: “Bush was misguided because he felt there should be a Chinese wall between basic research and applied research, and I have more of a Pasteur quadrant view that they complement each other and you really cannot have a separation”.

Industry respondents viewed these differences largely in terms of market fragmentation in place of strong, centralized key players; as one commented, innovation in healthcare has lagged because it is a highly regulated “cottage industry” that is fragmented and spread among many small players across the country.

These results collectively indicate that socio-political aspects should be factored into any metrics considerations seeking to portray ‘real’ outcomes on the ground.
VI. DISCUSSION

This chapter discusses the use of metrics and measures within and between the three research elements. System level implications for the organizing framework are discussed in the conclusions chapter.

a. Findings

i. Government

The goal of this research element was to answer the question of how the macroeconomic context of the federal SBIR and STTR programs influences the economic value relationship between academia and industry by comparing them against early stage investments made by venture capital investors. An underlying question addressed whether or not the small-business program may leverage academic research programs and possibly promote economic value creation through industry engagement.

The SBIR and STTR programs have become well established and key sources of proof-of-concept funding for small businesses innovating new technologies. While the original research and modelling behind many of these technologies occurs in higher education institutions, the projects that receive support from the SBIR and STTR programs are different to those conducting basic scientific research, as the driving aim of these programs is specifically to facilitate the commercialization of the new technology that emerges. Academic researchers acting as subcontractors, consultants, or technology innovators often play the key and central role in proposals to the SBIR or STTR program, and are employed (mainly) by the small business aiming to roll out the new technology.
In this way, SBIR and STTR program grants can significantly bolster the economic value relationship between academia and industry either by enabling the creation of a start-up company to market and own the new innovation, or by enabling an academic partnership with an existing small business that has the capacity and prior experience necessary to participate in these programs.

A condition of both programs is the inclusion of strong management plans to mitigate any conflicts of interest, which inevitably arise. For example, the current exemption of phase I SBIR and STTR program grants, occurring under the NIH policy on significant financial interests, is designed to promote the involvement of academia as well as the ‘translation’ of basic research into technology innovations that can aid human health, in accordance with the program’s federal mandate. This was found to be particularly important in cases where private sector participation is limited, such as with as yet unproven and thus high-risk technologies related to emerging research fields, or therapies for ‘orphan’ diseases. Since federal funding agencies and individual research universities may have significantly different policies regarding conflict of interest, this could lead to funding disruption. This is an issue that should be addressed in order to secure the intended trajectory of a particular project’s innovation goals and, ultimately, a more favorable economic value relationship between academia and industry.

**ii. Academia**

This research element focused on whether metrics could be used to quantify one particular aspect of the U.S. research enterprise: the transfer of scientific discoveries at research universities into commercial products and services for societal benefit. Supported by a qualitative process of interviews with seven technology transfer directors
comprising a wide range of research universities, specific institutionalized mechanisms for the movement of technical knowledge through both formal and informal channels and institutional frameworks were assessed. Collectively, the document review and interviews addressed the question of how and why academic technology transfer officers measure the economic value relationship between the education and training system and industry.

Usage patterns of metrics to monitor technology transfer from universities

Universities use a variety of metrics to monitor the emergent technology from their research endeavors, and that technology’s subsequent application. In line with existing studies, the six most common metrics observed in the current research were patents applied for and issued, license agreements, the number of new startups created and startup survival, and program revenue per million (West 2012). Alongside these, the interviews with key stakeholders revealed a number of other metrics to be important, notably collaborations with industry and other stakeholders (such as alumni and the local community), local economic development, knowledge acceleration and incubation, and a range of qualitative outcomes that some universities track, or are beginning to track. The latter in particular were deemed important in ‘telling the story’ of an original research innovation in a way that resonates with key stakeholders and ultimate goals, such as the local community and their quest for better health. In this way, such metrics were seen to be integrally linked with both institutional mission and the people these institutions were accountable to, including funders, students, political stakeholders and the region, among others.

In line with earlier studies, the current research agrees that typical inputs such as
collaboration, intermediate outputs such as innovation creation and knowledge acceleration, and final outcomes such as economic development, commonly used associated metrics may overlook informal or less visible avenues by which knowledge flows to and from universities (Walsh et al., 2003a, b). The current work has uncovered several more informal channels and metrics that are both used to transfer this knowledge and themselves impact upon it, including cultural change (on campus), institutions’ growing interest in an entrepreneurial focus, qualitative outcomes, and key stakeholder metrics associated with students, alumni, and faculty. The results section discussed the specific measures associated with each in detail; these are also summarized in the coding framework included in appendix F.

Use of technology transfer metrics in evaluation and planning

The research found that universities track metrics not only to report “progress” to university administrators - who, in turn, use the metrics in budget requests - but also as an accountability measure to their internal and external stakeholders, notably the student and local community. Budget-oriented metrics are then used to make the case to the (state) legislature that investments in R&D are worthwhile and to ask for additional resources. Metrics are rarely used to evaluate performance that has the goal of making changes to improve efficiencies or to target specific areas of investment.

It was also found that some universities are experimenting with performance-based metrics, such as pay-for-performance and other staff incentives for their technology transfer enterprise. However, creating a universal standard for these performance metrics has proven challenging given the widely varying research projects being pursued across different institutions.
Notwithstanding the small sample size, some noteworthy differences between different types of academic institutions were found. The higher focus of private institutions on cultural and attitudinal changes/effects may be due to the possibility that private institutions are more aligned with community needs and social cohesion, and may also seek to align their impact assessment with satisfying private donor priorities. The fact that equity relationships as a metric were only mentioned by private institutions could be due to regulations and policies prohibiting or limiting public institution ownership stakes in private ventures. Conversely, public institutions were more than twice as likely to factor economic development into their metrics which, arguably, could be in response to a higher sensitivity among state legislatures (who provide significant funding for public institutions) towards metrics associated with university contributions to economic resilience and growing the tax base. Institutions with a medical center were also much more likely to be concerned about using patents and revenue as impact metrics, which supports earlier similar findings presented in the literature.

Another interesting difference that emerged was that institutions with relatively smaller research and license revenues were most likely to be heavily focused on industry relationships and collaborations. This could indicate a certain level of resource dependence, whereby smaller institutions would have more incentive to engage with industry. It is important to remember, however, that all the institutions sampled are large research performers and license recipients on the comparative spectrum of U.S. research universities; they are thus bound by the imperative to find middle ground in order to operate reliably, but also still be incentivized to engage with stakeholders aside from federal funding agencies.
iii. Industry

The goal of this research element was to answer the question of how and why (the medtech) industry uses communication infrastructure in the form of digital tools at the firm level. An underlying question addressed how these digital innovation accelerators may affect the diffusion of knowledge across institutional boundaries and contribute to firm competitiveness.

Digital technologies are changing how companies innovate, interact, and do business. Consumer industries such as retail, electronics, and telecommunications are already heavy users of digital technologies to more closely connect to customers, better understand their needs, and be more responsive. As patients transition from passive care recipients to active value-seeking consumers in the wake of recent healthcare reform and the ACA, the medical technology industry is poised to see significant adoption and growth in digital innovation accelerators and crucial communication infrastructures.

Both the reference literature considered in the document review and the informant interviews agree that medtech companies are placing big bets on innovation. Stakeholders across the health industry segments of drugs, devices, and providers - which combined constitute the medtech industry - share common innovation goals ranging from enabling partnerships with insurers and providers, enhancing the efficiency and quality of clinical trials, improving patient engagement and disease management, creating new services and revenue streams, and building an innovation operating model that facilitates idea generation, collaboration, and rapid feedback. Leading companies are now investing in digital tools to create new revenue streams from data, optimize outcomes, and create tighter patient engagement in specific ways that are further described in this section.

The vast majority of medtech CEOs surveyed by PwC viewed technological
advances as the global trend that will transform their business the most during the next five years (PwC Global CEO Survey, 2014). Of the top five digital technologies of highest near-term strategic importance, four emerged both from the 2014 PwC digital IQ survey and in the industry interviews, including: social media, data mining, public/private cloud, and mobile apps, all discussed within their organizational context in the remainder of this section.

Digital opportunities to widen the innovation funnel, generate rapid feedback, and apply learnings

The PwC survey findings reveal that medtech companies named open innovation among the top approaches that will generate the most growth for their companies – more so than incubators, design thinking, and individual freedom for employees to explore innovative ideas. This finding is substantiated by the informant interviews, where innovation accelerators to support and promote this open innovation across the categories of emerging platforms, R&D analytics, social, mobile and cloud technologies, and integration were reported as the most important digital measures to support growth.

According to the 2014 PwC digital IQ survey, medtech executives named external social media as having the highest strategic importance to their business over the following three to five years, confirmed by interview informant feedback elaborating that some leading companies have already invested in open innovation platforms, such as InnoCentive, Kaggle, and Salesforce.com. This has primarily been done in order to share elements of research and development data that would otherwise be confined to individual organizations and researchers. The implications of this could be that the adoption of social media has the potential to release otherwise “invisible” or less
accessible research, which can significantly speed up innovation pathways by enabling innovation avenues such as collaboration with external stakeholders and parallel development.

According to the interviews, the most successful companies focus on digital opportunities to widen their innovation funnel, generate rapid feedback, and apply learnings. Leading companies are implementing organization-wide structures and practices that enable collaboration to increase the probability of producing the results they desire. Successful leaders invest in integrated, virtual networks of data repositories and environments that allow access to new sources of data and analytics, offering an entirely new way to interact and innovate. It was also found that many companies are participating in industry initiatives rather than building their own collaboration platforms. Through Project Data Sphere, competitor drug makers such as AstraZeneca, Pfizer and Sanofi work with research organizations to collect and share anonymized patient-level data from oncology studies. This, in turn, allows them to obtain and interpret “weak signals” that can help guide future development and clinical trials in a much faster feedback loop deriving early clinical knowledge from the data, enabling them to tailor new drugs as appropriately as possible to the corresponding patient candidates (discussed in greater detail under analytics below). The implication here is that collaborative, organization-wide as well as external structures and practices can ultimately enhance the likelihood of a medtech firm achieving their desired patient outputs and market results.

Proofs of concept are used to help prove value, develop foundational components, secure leadership endorsement, test the ability to scale, and mitigate risk. Companies are using simulation technology to design and test business models that rely on digital health
technologies and applications to deliver a better consumer experience, and build consistent capabilities to identify and scale promising concepts. One of the top digital investments that medtech companies are making is in simulation and scenario modeling, specifically to support this “pilot and prove” approach to speed up innovation effectiveness and efficiency. This underlines the importance that new digital technologies have from idea inception through to the market testing phase of a new medtech product, suggesting their adoption will become all the more necessary in order for these companies to remain innovative and competitive.

Mobile strategies to bring industry closer to patients

Consumer education has been the historic focus of most drug and device companies’ mobile strategies. However, companies are increasingly realizing they may be missing opportunities to use mobile technology in other ways that bring greater return. For example, the PwC Digital IQ survey shows an evolution over the last few years, in that medtech companies were most interested in mobile apps and technologies for employees in 2012, while in 2013 apps for consumers made the top five list, and in 2014 companies expected the number one priority to be consumer-patient facing mobile technologies, with 60% of companies predicting increased investment in consumer mobility, cloud, and sensing technologies.

From these and the interview findings, it can be inferred that leading companies are generally developing deeper, more direct mobile-based relationships with patients, not just with their internal employees or physician customers. Some medtech companies are also implementing consumer mobile apps that enable patients to better manage their care. Often, the quickest digital path to the patient will be through the care provider. For
example, one leading drug company uses technology originally built for the retail industry to enhance the patient experience upon an initial cancer diagnosis. Doctors then enter patient demographic data into the company’s digital app, which connects patients to ancillary support, such as the location of wigmakers in their areas. This creates a digital support environment where patients are seamlessly connected with the resources they need outside of the hospital environment, providing for a better patient experience and a continuous feedback loop on their needs and priorities to help medtech companies make future innovation decisions. It also suggests that adapting technology from other industry sectors is an innovative way to proceed that can also save a company time and resources.

According to the interview informants, technical alignment and coordination between medtech companies and providers will be crucial, as well as within medtech companies between the therapeutics they produce and the care processes around the diseases they treat. Companies need to prepare to round out a mobile product with additional services. Successful companies should first address the most acute “pain points” with their digital solutions, and then expand to add-on offerings.

Data mining, analytics, and quality insights

Data mining and analysis technologies topped the list of digital investments among drug and device companies in 2013, according to the 2014 PwC Digital IQ survey. This is confirmed by the interviews as some companies appear to have made strides in building infrastructure to align capabilities that are scattered across the organization. Major organizations such as Philips, Becton Dickinson, Pfizer, and Eli Lilly have built health informatics divisions or spin-off companies focused on looking for ways to develop new data-driven services for providers and insurers.
Leading companies are beginning to build a broader picture of customers and patients. As the results indicate, this broader picture is, in turn, enabling greater connectivity between patients, their records and the medical system, ultimately enabling more comprehensive care.

Despite this acknowledged importance of data mining and analytics, there was also found to be a gap in ‘real’ terms between obtaining and analyzing the data, and moving to concrete insight from this, based on which they could then proceed differently if necessary. The reasons behind this included the perceived poor quality, tardiness or incompleteness of the data obtained, combined with a lack of expertise at senior level to apply learning from the data to competitive advantage. The findings from the current study strongly indicate both that human and other resources should be invested into overcoming these obstacles, and that the yields are highly rewarding when they are.

Another major finding regarded the use of analytics to reduce risk. According to the 2014 PwC Digital IQ Survey, one-third of drug and device companies were predicted to invest more in data visualization technology over the next year. As a specific example from the interviews, Soluble Therapeutics, which provides drug formulation instrumentation and services, has invested in “neural net” technologies allowing scientists to predict the optimum combination of additives in three to four months versus 18 months. This clearly conveys the increased efficiency and risk management implicit in data-oriented digital innovations, as the resources and time saved via these could mean the difference between new market competitiveness and experiencing loss at a crucial point in many pharmaceutical companies’ processes, i.e. the bottleneck that can occur at R&D stage. Conversely, the implication here is that, should companies fail to harness the
full potential of data for risk mitigation in light of the aforementioned challenges, their outcomes and competitive edge could suffer.

**Integrating modern and core systems**

Even though many medtech companies have created smartphone apps for patients to monitor themselves and send data to clinicians, the PwC reference surveys found that only 18% of those companies are maximizing the use of new technologies and integrating these new data sources in core clinician workflows and Electronic Health Records (EHRs). Just 12% of device companies believe they are doing a good job of integrating this new data with their core R&D systems to drive innovation. This could be problematic given that successful companies need flexible tools that can be layered and accommodate evolving data sources such as EHRs, social media, and patients’ data themselves. As highlighted in the results section, typically medtech, especially providers, seek a one-off solution for each specific problem. However, the most successful strategy identified involves building adaptable infrastructure with broadly scalable and generic capability that not only solves the problem in question but can also be used to address others that inevitably emerge. Thus implementing sustainable solutions with a low change cost that are easy to configure and deploy is key. In other words, drug and device companies should combine their existing systems with new emergent technologies for the greatest return. This could lead not only to the bringing together of critical information otherwise present in silos across the organization, but crucially could then harness that new, integrated knowledge to help inform product improvements and therapy adjustments.
iv. Universal value drivers across academia and industry

The qualitative interviews found that while industry stakeholders were generally more inclined towards profit oriented economic measures, academia tended to veer towards less revenue focused metrics and measures that were tied to societal impact and social good. Stakeholders from both sides were broadly aligned that metrics should take into account both tangible outcomes, such as “the effectiveness of entrepreneurship… the advancement of knowledge, and then the best measure of collaboration,” (academia), and “real-world effectiveness and commercial success” (industry). The factor that united them most is adding intangible value by positively influencing the lives of patients and consumers in the case of industry, or by serving the community through the advancement of knowledge and economic development in the case of academic research institutions.

There is also agreement between academic and industry measures considering management theory derived innovation determinants. Respondents agreed about the importance of understanding the market, both in terms of advancing technology capabilities and engaging with evolving demand patterns, which aligns with a coupled technology push and market pull. Academia and industry also recognized service value and relationships in their shared necessity for a talented and interconnected workforce.

Finally, when organizing all the identified themes across academia and industry, an overarching pattern of three themes starts to emerge, where all of the identified metrics and measures either assess the overarching need for adequate and dependable resources, a need for a talented and interconnected workforce, or the need for efficient knowledge generation and diffusion. These overarching themes can play a significant role in the NIS model describing the economic value relationship between academia and industry, as discussed in the conclusions chapter.
b. Findings in relation to hypotheses

**H1. GOVERNMENT** – The federal SBIR/STTR federal funding programs exert a significant influence on the economic value relationship between academia and industry, equal or greater than that of comparable private venture capital investments. In light of this, the distributed nature of the individual funding program across federal agencies, private industry and academic institutions may give rise to policy divergences that might affect the most efficient translation of knowledge into outcomes of value to society.

The current study found that the federal SBIR/STTR programs significantly influence the academic-industry economic value relationship, especially at the most crucial proof-of-concept stage where the commercial viability of new research discoveries is tested for the first time. This is because the federal SBIR/STTR programs were found to provide both more total proof-of-concept capital as well as a substantially higher number of variably-funded projects than private venture capital investors. Significant shifts in year-on-year private venture capital availability also indicate the importance of the SBIR/STTR programs as a more constant economic catalyst acting on the dynamics between academia and industry, especially during times of economic austerity.

Significant discrepancies were found between the desired and even allowed university-industry economic engagement effected by different policy interpretations of the overarching federal SBIR/STTR mandate, the different federal SBIR/STTR funding agencies, and individual participating universities. These discrepancies imply that, in particular, a more universal interpretation and implementation of the conflict of interest
policies in line with the intended goals of the SBIR/STTR programs could promote more efficient knowledge generation and diffusion between academia and industry. Such an interpretation could also promote new commercial products, ultimately achieving outcomes of value to society.

**H2. ACADEMIA** – if the economic value relationship between academia and industry is driven by overarching product and factor market conditions shared between them, this relationship can be elucidated by identifying consensus technology transfer metrics and measures as well as the systematic research valuation divergences across the diverse spectrum of American research universities.

This study found that academic technology transfer consensus metrics can be identified across varying institutions and can be effectively organized by the nature of the circumstances in which they occur, or the channels via which they flow. These circumstances and channels include innovation creation, knowledge acceleration and incubation, collaborations, cultural change (on campus), entrepreneurial focus, economic development, and qualitative outcomes. In the aggregate, these academic consensus metrics can help to define adequate, dependable resources as the overarching product market theme, and a talented and interconnected workforce as the overarching factor market theme driving the economic value relationship between academia and industry.

However, it should also be noted that distinct differences exist in how universities view and assess their role in society through entrepreneurial engagement and economic development, between both public and private institutions as well as between organizations with differing organizational research expenditures and license revenues.
H3. INDUSTRY – if the economic value relationship between academia and industry is driven by overarching product and factor market conditions shared between them, these can be elucidated by identifying the consensus measures for the communications infrastructures that enable innovation across organizational boundaries. Furthermore, within a specific industry (such as the medical technology industry), digital innovation accelerators are a significant driver for firm competitiveness that can be successfully identified and categorized for a more in-depth characterization of the diffusion of knowledge across innovation determinants.

A number of digital tools were identified in this research across the medical technology industry as consensus measures for the communication infrastructures enabling innovation across organizational boundaries. They can effectively be classified as: emerging technology platforms; social, mobile and cloud technologies; R&D analytics; new skill-sets; and integration. In the aggregate, these industry consensus measures can help to define adequate, dependable resources as the overarching product market theme, and a talented and interconnected workforce as the overarching factor market theme driving the economic value relationship between academia and industry.

c. Strengths

The main strengths of this study that add validity lie in its qualitative approach and diverse study population. Existing literature in the current field typically either focuses on an academic or industry perspectives but not both, often relying exclusively on published data sources such as the AUTM survey or USPTO patent data. These have
considerable known limitations with regard to eliciting several of the most important value dimensions related to measuring human capital, collaborative engagements, and societal outcomes. Semi-structured interviews thus made it possible to obtain information on both known metrics and measures identified through the document review, as well as previously unknown metrics and measures, with the additional benefit of exploring the key context of how decision makers value, use and interpret metrics within their respective organizations. By pursuing an academic as well as an industry perspective, it became possible to triangulate these results and identify overarching themes that define the academic-industry economic value relationship, and the product and factor market conditions driving this relationship. In addition to the richness of perspectives, a study scope encompassing both academia and industry also exposed two different literature perspectives on innovation models at the national and firm level, resulting in an adapted framework which included a number of innovation determinants typically not considered beyond the realm of firm level management practice.

d. Limitations

A number of key limitations and challenges arose over the course of this research. The main limitation is the small sample size of the primary data gathering aspect, comprised of seven academic technology transfer and eight medical technology industry informants. However, the qualitative nature of the research meant that depth, rather than breadth, was of the essence, and sufficient respondents were interviewed to enable the ‘saturation point’ of key themes to be reached. Moreover, given the seniority of the informants and the size and market share of the organizations they represent, the sample
in its entirety was believed to be sufficiently strong to draw meaningful, generalizable conclusions on the use of measures and metrics for assessing the economic value relationship between academia and industry, as well as their practical utility for stakeholders, thus allowing general conclusions on consensus and priority themes for improved innovation system modeling to be made. However, some of the conclusions related to the fixed variables within each of the study elements - especially those differences noted between small/large or public/private universities - while providing an interesting glimpse for possible future research directions cannot be considered conclusive owing to the small size of the respective samples within each of the research elements.

Some limitations should also be noted with regard to the study design (the semi-structured elite interviewee approach), and a possible selection bias relating to both academic and industry interview informants. All informants were top executives within their respective organizations and this should be considered “elite interviewees”. As such, while they are particularly well informed and knowledgeable about the research topic, they also serve as spokespeople for their respective organizations. The latter incurs the risk of receiving rehearsed answers from them within the scope of the research interviews which may echo interviewees’ default public stance, rather than being ‘fresh’ answers that have not been elucidated in previous public contexts. Given the level of background research conducted in preparation for each of the interviews, which included inside knowledge obtained from the National Academies committee members and PwC consulting practice leaders (who have longstanding relationships with most of the interviewees and/or their respective organizations, this risk was believed to be
outweighed by the opportunity for particularly rich and informed answers. However, it should also be noted that all informants were provided the interview questions in advance and, as such, could have prepared or even rehearsed their answers. As a counterbalance to this potential limitation, the semi-structured nature of the interviews, enabling the free pursuit of specific aspects of the interview depending on the answers to particular questions, somewhat mitigated this weakness.

The second study design limitation centered around the fact that, even though the sampling frame for each study element was rationally designed to draw a representative sample, the final selection of informants was governed by the organizations where the research elements were conducted; that is, the National Academies Committee on Assessing the Value of Research and the PwC Health Research Industry executive team, respectively. While their knowledge of the opinion leaders related to each of the study elements was valuable in identifying the most information-rich cases needed to maximize the yield from the fairly small sample, this may also have introduced selection bias based on the limitations of the professional networks of the decision makers. Two possible indications of this are the lack of West-Coast representation for the academic interviews (there was a fairly even North-South geographic distribution), and the significant representation of active PwC clients (half of the sample) for the industry interviews.

Additionally, some organizational types were purposefully excluded from this research. For the academic research elements, only organizations among the top 50 for both research expenditures and license revenue as reported by the 2014 AUTM STATT database were included in the study. A number of studies have shown resource dependence to be a significant factor in the collection and active use of technology
transfer metrics by academic institutions, including the APLU New Metrics project that was reviewed for this research. A significant level of research and licensing activity are typically required for universities to build the administrative capacity to actively collect technology transfer metrics beyond the core set reported by AUTM, and to then engage in impact assessment and other evaluations of those metrics. These considerations, alongside the imperative of the qualitative semi-structured interview design, meant that the selection of particularly information-rich cases from larger institutions was deemed the most appropriate approach for this study.

For the industry research element, only medical technology companies spanning the pharma-life science, medical device, and provider health industry sectors were included. Payers and healthcare informatics companies were purposefully excluded from the study because the document review showed significantly different dynamics underlying the use of digital tools from the other health industries considered. While healthcare informatics and payer organizations are an important part of the healthcare innovation ecosystem, and the communication infrastructures that drive their innovation are worth studying, since they are typically not focused on research-driven innovation and the digital accelerators associated with this particular innovation dimension they fell outside of the scope of this dissertation.

For this dissertation, the government research element was considered using a researcher case study and not through interviews with government officials or policymakers, which were excluded from this research and could thus have introduced an omission bias. However, this omission was deliberately enacted in order to focus the research on the economic value relationship between academia and industry, on which
government can have an influence through funding policy and regulations, but is typically not a transactional stakeholder.

This work took a national perspective on the innovation system using the National Innovation System framework and, as such, chose to ignore the regional effects that state level governments and regional innovation clusters can have on innovation systems. Another set of distinct stakeholders who are often active on a regional level based on particular needs in a community are philanthropies and other non-profits aimed at technology innovation and entrepreneurship. Both fell outside of the scope of this work, but would be an interesting direction for future research.

Finally, some possible limitations should also be noted related to the study context. The academic research element was conducted by the researcher as a fellow with the National Academies of Science under a federal mandate from congress, while the industry research element was conducted by the researcher as a visiting analyst with the PriceWaterhouseCoopers Health Research Institute, which provides consulting services to the health industries studied. As such, some of the interview responses could have been influenced by the semi-governmental and industry auspices they were conducted under. For example, informants might have included political considerations if they were either a recipient of federal funding (to which governmental decision makers the National Academies reports their findings), or a PwC strategy consulting client in which the company might already be invested. Furthermore, the different research elements were conducted separately and sequentially (academia between the fall of 2012 and the spring of 2014, and industry between the fall of 2013 and the summer of 2014), with each leading to a different report based on their area of focus.
VII. CONCLUSIONS

Nations, diverse organizations such as public research universities, and private industry all use metrics for a variety of purposes, including retrospectively evaluating the impact of research projects, assessing the dissemination of technology, and examining the return on investment of particular endeavors such as biomedical research. Numerous studies have conclusively demonstrated that no one single metric can be applied in isolation. Taking this into account, the current study has conducted the following: a comprehensive evaluation of current parameters used to measure the economic value of research; a qualitative investigation into the technology transfer metrics that can reflect the economic value relationship between academia and industry; and current communication infrastructure modes in the form of digital innovation accelerators in the medtech industry. In so doing, a number of key, overarching themes emerged that have implications for the organizing NIS framework. This chapter presents these themes and their implications for the NIS measurement model.

a. System-level value drivers

A talented and interconnected workforce

The research found that a critical input into the innovation trajectory between academia and industry is that of a talented and interconnected workforce. This is typically comprised of experts, stakeholders in and beneficiaries of the fields of science, technology, engineering, and mathematics (STEM) education and training, as well as career technical (i.e., vocational) training. Beyond these, the system encompasses many
other aspects including immigration, students/alumni, professional partnerships and networks, and a research environment conducive to creativity that fosters and boosts the ingenuity of talented researchers. Critical to these actors and the interactions between them that ultimately feed a talented and interconnected workforce is the culture within which they operate; namely, the institutional or industry/firm-led guidelines as to the extent to which they are able to consider and act on the demand for and measurement of various indicators that can comprise research value metrics.

**Adequate and dependable resources**

Funding, scientific infrastructure such as that made possible by world-class research universities, national laboratories, and other research institutions are all key determinants and resources driving research innovation. This is because such resources can facilitate the vital support that a research process may need, enabling the individual project to achieve and maintain sophisticated communication, other necessary infrastructures, and the optimum human capital. In particular, it was found that government support for proof-of-concept research, such as the SBIR/STTR programs are vital in providing these resources. However, the implications of these findings collectively are that science, and the value creation it generates, must be managed not only through particular programs but also through multiple, contextual considerations that are able to maintain a focus on certain overarching goals. For this purpose, i.e. portfolio assessment, performance measures can be seen as useful, whether these are based on research outputs, such as patents or publications, or on the trajectory towards and achievement of a set goal.
World-class knowledge generation and diffusion in all major areas of science

Stakeholders across all research elements in this study strongly implied that a successful innovation framework is one where excellence and high intellectual merit across all major areas of science characterize the execution of basic research. This success was also attributed to the efficient dissemination of the emergent knowledge and technologies by combining discoveries across different fields and adapting them into value-added market goods and services.

Thus another major element of this success is the capacity to form and maintain strategic partnerships which then facilitate the production of world-class basic research. Such alliances are often the seedbed of new discoveries given their propensity to bring together individuals with different experience, training and perspectives, such as academic researchers and applied industry researcher. Moreover, the ability of industry to invest in academic research is usually made possible by the existence of university-industry partnerships, which also provide scope for the commercialization of research discoveries. Thereafter, an iterative effect occurs, whereby strong partnerships bolster scientific and technological research in both universities and industry, following which the new inventions and even manufacturing feed back into the research process, enabling further innovation.

i. Proposed measurement framework

An intricate research system determines the economic value relationship between academia and industry, one that can be characterized as pluralistic, decentralized, meritocratic, competitive, and entrepreneurial. Given this complexity, it is inevitably impossible to predict the precise nature of the innovations resulting from specific
research discoveries, or the types of research which would engender transformative innovations if other research and approaches were not present. That is to say, it is extremely difficult to ‘control for’ the isolated impact of a single research endeavor. Consequently, the current research concludes that prioritizing the system drivers of talent, resources, and knowledge generation and diffusion will arguably ensure that new discoveries continue to emerge from academia and industry across the innovation system.

Measures designed around adequate, dependable resources as the most prominent product market theme, and others around a talented and interconnected workforce as the most prominent factor market theme, are proposed for a more effective measurement framework for the economic value relationship between academia and industry, leading to university-industry innovation capacity which might be most appropriately evaluated through measures for knowledge generation and diffusion. These would then facilitate the construction of measures around knowledge generation and diffusion that could evaluate university-industry innovation capacity. This modified, improved NIS measurement framework could then be applied in a more ‘hands-on’ manner by stakeholders across government, academia and industry, thus enabling the system to yield more measurable benefits. The proposed model is provided in figure 22.
b. Implications

Publications, and technology transfer such as patents and licenses, represent research outputs that can usefully be quantified by a range of metrics. In particular, these outputs can then lead to the assessment of certain research outcomes, particularly in the arena of applied research focused on a specific goal; they can also be useful in discerning a university’s research impact on the regional economy, thus serving to increase the societal benefits of research. Nevertheless, research impact metrics should also be
considered with caution, in light of the recognition that impact assessments necessitate both individual, set metrics and a system-level context. These implications suggest that, at a policy level, current measures are not sufficiently robust to guide national-level decisions about the research investments best placed to bolster and disseminate scientific benefits. Existing measures can, however, be seen as useful to both academic and industry stakeholders in aiding them better to comprehend and shape their shared economic value relationship of research driven innovation.

There has been a long tradition of collaboration between industry and American universities in research projects and other alliances. These activities have consistently benefited from a mutual flow of people and ideas between industrial and academic research settings and expertise. Several factors have facilitated this partnership tradition, notably the historic structure of the U.S. national higher education system, as well as elements externally acting on academia, such as labor markets absorbing a relatively high frequency of researchers’ domestic inter-institutional mobility, and private venture capital for innovation development. These collaborations have usually included a high rate of university inventions being patented and licensed to industry. It should also be noted, however, that these interactions between U.S. universities and industry innovation in industry throughout the past century and the beginning of the 21st have been mitigated by a number of different factors, ranging from the publication of research advances, the capacity building of students and faculty, and industry-sponsored research, among others. These factors operate both in parallel interdependently, with their relative influence on the interaction and information flow between industrial and academic researchers varying significantly across diverse fields of research.
Reflecting these complexities and their positioning in both regional economies and the national context, it could initially be said that university technology transfer programs can be harnessed to the achievement of a range of institutional goals. However, it soon becomes clear that these goals are not always compatible or mutually consistent; revenue-maximizing licensing strategies, for example, are arguably shortsighted. These challenges imply that technology transfer programs necessitate the adoption of policy priorities, which are then explicitly correlated with policies in operation. The metrics subsequently establish to assess universities technology transfer performance and to support industrial innovation should thus be in line with the individual goals of a given university or research institute. These metrics also need to factor in the full range of influencing elements and channels which facilitate a university’s research influence on industrial innovation, including faculty research publications, student training and placements, the number and subsequent survival of faculty- or student-founded firms, and the number of patents and licenses.

Given the current lack of data reflecting these elements at most U.S. universities, as well as the imperative for metrics to be customized to the cultural context and mission of individual universities, it would appear to be unfeasible and misrepresentative for federal agencies or other government evaluators to impose a single, one-size-fits-all set of metrics with which to measure the technology transfer performance of all U.S. universities. Rather, such a framework should seek to recognize and adapt to the institutional heterogeneity that has historically been a strength of the U.S. higher education system. This is because, crucially, such institutional heterogeneity urges the need for U.S. universities to employ flexibility and policy diversity in supporting
academia’s interactions with industry and the commercialization of academic research advances. There has, as yet, been no single structure established for implementing and overseeing the patenting, licensing and related activities in university-industry collaboration by the Bayh-Dole Act or other relevant federal policies. Despite this, over the past three decades since the act’s passage, American research institutions have adopted a slow pace in engaging with the different approaches available for managing these outputs. The implications of this study strongly point to the fact that this pace should be allowed to accelerate, and that universities’ efforts to evaluate the rigor of alternative approaches towards industry collaboration should be encouraged by federal agencies, industry, and other stakeholders. Beyond this key implication, emphasis must still be placed on the likelihood that no single approach is likely to prove relevant or rigorous across the myriad and unique academic institutions and private firms involved in federally funded research and industry collaboration.

With regard to communication infrastructure, the clear implications of this research are that traditional medtech companies using outdated and static information technologies will encounter numerous challenges in meeting the needs and demands of the next generation of consumers. If these firms neglect to construct a digital strategy conducive to enabling its innovative progress, they risk being pushed out of the market by competitors who will embrace these new means, and thus may not locate the opportunities to develop new revenue sources. Conversely, businesses that do choose to invest in adaptable technology platforms, including sophisticated analytics, social, mobile and cloud technologies, new skill sets, and data-sharing relationships will have a greater chance of rapidly achieving groundbreaking innovations.
c. Recommendations

Given the importance of metrics that can track and assess research activities, outputs, and technology transfer, it is imperative to improve both the measures that exist and the underlying data on which they are based. While new areas such as network analysis could bear good fruit in terms of developing new measures, arguably greater benefits can be enacted by placing the onus on the key system-level value drivers detailed in this study: talent, resources, and knowledge generation and diffusion. Metrics tailored to these determinants and the specific product and factor market conditions underpinning them would provide deeper insights not only into these vital elements and how they interrelate, but also into the academic-industry value relationship within the innovation system. This study indicates that such new measures might include, for example, indicators relating to: the knowledge trajectory in specific scientific fields, human and knowledge capital, the flow of foreign research talent, international benchmarking of research performance, portfolio analyses of federal research investments by field of science, and the transferability and reproducibility of research.

In order to construct these measures, further research and data are needed. For example, assessing talent could include the use of network-measuring metrics, and the creation of new indicators of human and knowledge capital drawn from existing longitudinal datasets managed by organizations such as the U.S. Census Bureau, NCSES, and the U.S. Bureau of Labor Statistics. STEM labor mobility indicators could additionally shed light on the career progression of scientific researchers and recent STEM graduates by tracking individual pathways and posts in industry, government and academia. Finally, full-text dissertation databases could be mined for data to then create...
indicators for emerging research topics; this would potentially enable a more accurate correlation between STEM training and industry demand for particular skills.

Industry players have often been reluctant to fund high-risk proof-of-concept research. A more enabling policy environment could therefore be created by implementing business incentives to engage with such research, which would ultimately strengthen the route from research to innovation. Given that private industry is alert to the short- and medium-term needs which such proof-of-concept research could serve, new government regulations and incentivizing policies - as well as increased public-private partnerships - could then motivate industry stakeholders to contribute to the investment gap between a research discovery and its final industry use. This more enabling policy landscape would also arguably contribute to better honoring taxpayers’ investments, particularly with regard to harder-to-treat orphan diseases; in this context, there exists an urgency to facilitate academic partnerships with small businesses and not impede them. One way in which policy could mandate U.S. Universities to serve the public interest would be for federal research agencies such as the NIH to require universities receiving Public Health Service funding to comply with the phase I SBIR/STTR exemption. As the technology emergent from the program funding moves to Phase II, the budget at that stage would then enable the technology-commercializing firm to operate more autonomously and thus reduce potential conflict of interest with academic innovators/partners.

d. Future research

An interesting innovation dimension not studied in this work is the impact of
states and regions on the innovation system. Both the federal government as well as a number of individual states have recently implemented innovation legislation built on the theory of “regional innovation clusters,” aimed at supporting and growing innovation clusters on a regional basis. Shifting the regulatory context to the state level, especially considering those states that have recently adopted comprehensive innovation support programs associated with robust investments such as the $700 million Ohio Third Frontier program⁸, would be an interesting direction for future research.

While the academic study sample was small, some interesting indications were observed regarding possibly significant differences in research valuation and assessment between public and private universities, as well as between universities with larger as opposed to smaller research budgets. Future work with a larger sample frame including these different fixed variables could prove valuable in validating the preliminary findings of this work.

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⁸ Available: https://development.ohio.gov/bs_thirdfrontier/ [February 2016]
VI. REFERENCES


Shipp, S., Mitchell, N., and Lal, B. (2009). Portfolio Evaluation of the National Science Foundation’s Grants Program for the Department-Level Reform (DLR) of


APPENDICES

a. Discussion Guide for Academic Research Element

What types of technology transfer metrics do universities collect and how do they use them?

The National Academies’ National Research Council (NRC) is conducting a study to investigate the pathways through which research contributes to our economy and well-being and serves other national goals. For this part of the study, we are preparing an overview of the types of technology transfer metrics that universities collect and use.

1. How do universities measure technology transfer success? What metrics do they use (e.g., attracting industry funding for research, a patent, a license, a spinoff)? What qualitative information do they collect?
2. Do universities capture the variety of university-industry partnerships? How do they determine what constitutes successful ones?
3. How do metrics and other information feedback to research programs influence its direction?

Other Stakeholders:

4. Who are other stakeholders that use university technology transfer metrics?
   a. University officials (specify)?
   b. Funding agencies (specify)?
   c. State governments?
   d. Congress?
5. For each stakeholder, we would like to understand what metrics they use and how do they use them? For example,
   a. To track performance,
   b. For evaluation and planning, and/or
   c. For other purposes.
6. Of what metrics schemes are you aware (Association of University Technology Managers (AUTM) survey, STAR Metrics …)? If relevant, in which ones do you participate (use)?
7. What recommendation do you have about the collection and use of technology transfer metrics? (Optional: If you could choose three metrics, what would they be and why?)
8. How would you propose to measure the quality of research output from universities and other research institutions that receive federal support?
9. How would you propose to measure the potential societal impact of research in advancing national goals?
b. Interview Request and Discussion Guide for Industry Research Element

I am working with PwC's Health Research Institute (HRI: www.pwc.com/hri ) on a report that takes a look at the IT/digital accelerators and innovation. This will be a follow-on report to a recently released HRI Medtech Innovation Report (copy attached), to highlight what kinds of technologies and approaches leading pharma and life sciences companies are investing in to reduce trial startup times, mitigate trial risks, understand health outcomes, and develop new service offerings for providers and patients.

The key hypothesis is:
To deliver on consumer expectations for convenience and value in the new health economy, healthcare companies need the right mix of IT/digital tools to accelerate innovation in R&D and across the business as new entrants to the industry start to chip away at the market. Industry leaders are investing in emerging technology platforms, social, mobile and cloud technologies, R&D analytics, new skill sets, and data-sharing relationships to help them achieve breakthrough innovation faster.

I believe some of your work would provide some interesting insight for our report, and I was hoping you might be interested and available for a 30-minute phone interview next week.

You will have the opportunity to be quoted in the report, but you will be able to approve/refine your quotes before we publish. We will not publish any quotes or company references without your permission. We will share the report with you when it launches later this summer. Many thanks in advance for considering this request.

Interview guide:
1. What is the primary focus of your IT/digital strategies? Is the focus more on accelerating R&D innovation or service/business innovation?
2. What IT/digital solutions are you investing in right now? In the next 3-5 years?
3. To what extent are your IT/digital investments aligned with the strategic goals of the company?
4. What is your company's biggest IT/digital barrier to accelerating innovation? Data integration? Cultural acceptance? Scalability?
5. To what extent has your company used social and/or mobile platforms to engage internal and external stakeholders?
6. To what extent is your company merging modern technologies (like social, mobile, analytics, and cloud) with existing core systems (e.g., R&D)?
c. Annotated Bibliography of Selected Studies

This appendix was adapted from (National Research Council, 2014)


This report explores avenues in which changes in U.S. policies and practice might have the greatest impact on research innovations. Because transdisciplinary and trans-sector research play particularly important roles in advancing scientific discovery, the report recommends pursuing a deep conceptual and functional connectedness across scientific disciplines (particularly the physical and life sciences) and fostering cooperative, synergistic inter-actions among academia, government, and the private sector.


This report reviews the development in other countries of performance indicators of scientific research and their use in allocating funds. The panel concludes that several performance metrics are available; however, no single indicator, set of indicators, or assessment strategy offers an ideal solution in research assessment con-texts for natural sciences and engineering discovery research. In light of this observation, the panel recommends four guiding principles to support research funding agencies undertaking science assessments in support of budget allocation: context matters, do no harm, transparency is critical, and expert judgment remains invaluable.


This report presents a careful and critical review of the different approaches to measuring research impacts. Measuring return on investment can be tricky because the impact of research depends on a complex web of factors, such as how quickly the scientific community becomes aware of the findings, the success of follow-up research, how quickly the findings are put to practical use, the likelihood of success (high-impact research often entails greater risk), and how “positive impact” is defined. Having issued that warning, the report describes how the impacts of scientific research can be grouped into eight broad categories: effective teaching; advances in knowledge; encouraging additional investment
by other parties; financial returns; and economic, social, environmental, and intangible (e.g., national reputation) outcomes. Impact in these categories can be assessed using the following methods, although the authors emphasize that none of the current measures can provide definitive results: input measures, output measures and benchmarking (e.g., bibliometric measures), peer review by expert panels, researchers’ anecdotes about the benefits of their work, detailed case studies of research outcomes, cost-benefit analyses, hindsight studies, surveys (e.g., stakeholder surveys to assess the perceived significance of a project; commercialization surveys to quantify staff, spin-off companies, and patents), economic models, and econometric analyses.


This study analyzes six research evaluation frameworks in various countries, also providing a brief overview of eight additional frameworks. It presents a guide to the key considerations entailed in developing approaches to research evaluation. The report also describes several tools used in research evaluation. The report emphasizes that perennial challenges to research evaluation (e.g., attribution, contribution, time lag between research and outcome, level of performance) need to be addressed in the development of evaluative methods. Furthermore, frameworks and tools should be tailored to the purpose of the evaluation and the type of material being evaluated. Research evaluation tools typically fall into one of two groups: formative tools, which are flexible and able to deal with cross-disciplinary and multidisciplinary assessment; and summative tools, which do not require judgment or interpretation and are quantitative, scalable, transparent, comparable, and suitable for high-frequency longitudinal use. These two types of evaluation tools serve different needs; multiple methods are required if researchers’ needs span both groups. The report notes further that research evaluation approaches should suit their wider context. Different approaches may be acceptable and credible in different environments, and it is important to consider this when developing a framework.


This is the second in a series of reports exploring how the United Kingdom can gain the most value from publicly funded research. The report stresses the importance of moving from simple measures of impact, such as university spin-offs and patents, to a more nuanced understanding of the connections between the public and private sectors in a system of knowledge production and innovation. The report concludes that narratives, rather than economic values, may be the most effective way to assess the impacts of
research and the pathways to these impacts. The narrative format would allow for a description of the various factors influencing impact and therefore avoid many of the challenges inherent in developing useful metrics.


In this paper, Mazzucato argues that opportunities are being missed if recent developments in the innovation literature, economic theory in general, and experience from elsewhere in the world are not considered in setting UK policy. The paper aims to provoke a radical change in the understanding of the government’s role in economic policy. The author hopes to spark a conversation about how the state can use its power to specify the problems it wishes to solve through technological advances and innovation, thereby ensuring that those advances are able to take place. The paper concludes that a more entrepreneurial economy would be beneficial to the United Kingdom, and that such an economy would not necessarily require the British government to withdraw but to lead. The paper provides 10 recommendations for increasing innovation through various efforts, including policy changes, tax incentives, and elimination of existing roadblocks.


This paper concludes that there is no simple answer to the question, “What are the economic and social benefits of basic research?” The authors note that the benefits of publicly funded research come in a variety of forms, flowing through a variety of channels and over differing time scales. Seven relatively distinct mechanisms or “channels” are described through which benefits from research flow into the economy and society. The findings reported show that the benefits are substantial, certainly sufficient to justify considerable government investment in basic research. The findings reveal seven main mechanisms or “exploitation channels” through which the benefits of basic research may flow to the economy or to society at large: (1) increase in the stock of useful knowledge, (2) supply of skilled graduates and researchers, (3) creation of new scientific instrumentation and methodologies, (4) development of networks and stimulation of social interactions, (5) enhancement of problem-solving capacity, (6) creation of new firms, and (7) provision of social knowledge.


This report recommends that the United States be among the leaders in all major areas of science, and notes that the nation’s ability to achieve world-class basic research could be
tracked with the qualitative metric of international benchmarking. In particular, the report suggests that maintaining a world standard of excellence in all fields will help ensure that the United States can “apply and extend scientific advances quickly no matter when or where in the world they occur.” To this end, the federal investment must be vigorous enough to support research across the full spectrum of scientific and technological investigation.


This is a follow-up to the 1993 National Research Council report Science, Technology, and the Federal Government: National Goals for a New Era, summarized above. In this report, international benchmarking is used to assess U.S. performance in the fields of immunology, materials science and engineering, and mathematics. The report identifies eight factors predicted to have the greatest influence on the quality of future U.S. research performance relative to other nations: (1) the intellectual quality of researchers and the ability to attract talented researchers; (2) the ability to strengthen interdisciplinary research; (3) the ability to maintain strong, research-based graduate education; (4) the ability to maintain a strong technological infrastructure; (5) cooperation among the governmental, industrial, and academic sectors; (6) increased competition from Europe and other countries; (7) a shift in emphasis toward health maintenance organizations in clinical research; and (8) adequate funding and other resources. Metrics focused on these eight factors could help sustain the world-class quality of basic research as an essential pillar of the research system.


A draft of the working group’s report notes that the tools, techniques, and data needed to develop comprehensive measures of value are still in the early phases of development, and therefore it is not possible to assess the value of NIH-funded biomedical research at this time. However, the draft report notes six strategies that could enhance assessment efforts: (1) a sustained investment in NIH’s data infrastructure, and dedicated funds and a mechanism to support assessment projects; (2) a focus on clear connections between the generation and impact of scientific knowledge; (3) a movement toward “credible, interpretable, and useful assessments of the value of NIH” that “attribute outcomes to all contributors and adopt a timeframe that is broad enough to include sufficient time for discovery to be applied”; (4) partner- ships with stakeholders to complete the assessments; (5) establishment of a trans-NIH Committee on Assessments that would develop a strategy and process for assessing the value of NIH-sponsored research; and (6) beginning assessment activities with a clear statement of purpose for the exercise and a strong strategy for communicating and disseminating the assessment results.

The workshop participants noted the myriad challenges to developing a universal measure of research impact that spans all scientific fields (e.g., the returns of research occur on an unpredictable timeline and depend on further efforts by individuals, society, or other organizations; the definition of “positive impact” can be variable; intangible outcomes such as knowledge, national reputation, and failure are crucial to success but difficult to measure). With that caveat, the participants identified six target areas in which the short- and long-term economic and noneconomic impacts of federal research funding can be assessed: (1) economic growth, (2) productivity, (3) employment, (4) social values (e.g., environmental protection and food security), (5) public goods (e.g., national security), and (6) the behavior of decision makers and the public.


This report, referred to as the “tire-tracks” report for its famous diagram, shows how investments in academic and industry research are linked to the creation of new information technology (IT) industries with more than $1 billion in annual revenue. It describes how industry builds on government-funded university research and illustrates the interdependencies among subfields of computing and communications research. The report concludes that properly managed, publicly funded research in IT will continue to create important new technologies and industries, with an unpredictable timeline from the discovery of a new idea to the creation of a highly profitable industry. The complex partnerships among government, industry, and universities—and the federal government’s support of basic research—are critical to the success of IT, and consequently to national security and economic and societal well-being.


This report recommends the 10 most important actions that Congress, state governments, research universities, and others can take to maintain U.S. excellence in research that will help achieve national goals. For each recommendation, the report outlines an implementation strategy, budget considerations, and expected outcomes. Specifically, the report recommends that the federal government (1) adopt stable and effective policies,
practices, and funding for university research and development (R&D) and graduate education; (2) provide greater autonomy for public research universities so they can leverage local and regional strengths to compete strategically and respond with agility to new opportunities; (3) strengthen the business role in the research partnership, facilitating the transfer of knowledge, ideas, and technology to society and accelerating “time to innovation” to achieve national goals; (4) increase university cost-effectiveness and productivity to provide a greater return on investment for taxpayers, philanthropists, corporations, foundations, and other research sponsors; (5) create a “Strategic Investment Program” that funds initiatives at research universities critical to advancing education and research in areas of key national priority; (6) the federal government and other research sponsors should strive to cover the full costs of research projects and other activities they procure from research universities in a consistent and transparent manner; (7) reduce or eliminate regulations that increase administrative costs, impede research productivity, and deflect creative energy without substantially improving the research environment; (8) improve the capacity of graduate programs to attract talented students by addressing issues such as attrition rates, time to degree, funding, and alignment with both student career opportunities and national interests; (9) secure for the United States the full benefits of education for all Americans, including women and underrepresented minorities, in science, mathematics, engineering, and technology (STEM); and (10) ensure that the United States will continue to benefit strongly from the participation of international students and scholars in the nation’s research enterprise.


This report emphasizes the importance of sustaining global leadership in the commercialization of innovation, which is vital to America’s security, its role as a world power, and the welfare of its people. Both advanced and emerging nations are pursuing policies and programs that appear to be less constrained than those in the United States. This report argues that more attention should be paid to achieving and benefiting from the outputs of innovation—the commercial products, the industries, and particularly high-quality jobs to restore full employment. America’s economic and national security future depends on success in this endeavor.

This report examines science and technology indicators from a number of nations in North America, Europe, Asia, and Australia and offers recommendations on improving the U.S. National Science Foundation’s science and technology indicators to better enable the agency to respond to changing policy concerns. In particular, the report examines the use of specific metrics for measuring networks, as well as human and knowledge capital, and notes that indicators of human and knowledge capital could be created by linking existing longitudinal data from agencies and organizations such as the U.S. Census Bureau, the National Center for Science and Engineering Statistics (NCSES), and the Bureau of Labor Statistics. In addition, indicators could be generated to track the flow of knowledge in specific fields of science, which could potentially help answer questions about STEM labor mobility and provide the information needed to better match STEM training to the demand for particular skills. The report offers a number of recommendations for NCSES, including making data quality a top priority, and working with other government agencies and departments to make existing data available and linkable between agencies.


This OECD report describes the knowledge-based economy and explains why current understanding of this economy is constrained by the extent and quality of the available knowledge-related indicators. The report emphasizes the need to produce and disseminate the specific genres of knowledge that are needed at the time. It distinguishes the “know-what” (knowledge of facts and information) from the “know-why” (knowledge of the laws and principles of nature), the “know-how” (capabilities and practical skills), and the “know-who” (knowing who has each type of knowledge). A well-functioning system cannot simply rely on the knowledge of information and underlying principles gained in school and through basic research (i.e., the know-what and know-why). The system also depends on workers with practical skills (i.e., the know-how) and the invaluable awareness of other workers and their expertise, which is gained through networks, partnerships, and other professional relationships. The report notes four areas for indicator development (knowledge stocks and flows, knowledge rates of return, knowledge networks, and knowledge and learning) and makes recommendations on the development of indicators of the knowledge-based economy, noting that such indicators must start with improvements to more traditional input indicators of R&D expenditures and research personnel. Better indicators also are needed of knowledge stocks and flows, particularly relating to the diffusion of information technologies, in both the manufacturing and service sectors; social and private rates of return on knowledge investments to better gauge the impact of technology on productivity and growth; the functioning of knowledge networks and national innovation systems; and the development of human capital.


This report explores the web of interactions among institutions, researchers, and private firms that make up national innovation systems and identifies best practices. It notes that an effective innovation system produces revolutionary advances both within the research
system and beyond, relying on networks of institutions and researchers to integrate, transform, and disseminate discoveries in diverse fields. The report reflects the first phase of a two-phase OECD project to map knowledge flows and develop indicators for assessing national innovation systems.


This report concludes that among the major instruments of government policy, both fiscal incentives and direct funding stimulate business-funded R&D, whereas government- and university-performed research appear to have a crowding-out effect. In short, when the purpose is to increase business-funded R&D, it is apparently better to give money than knowledge to business. However, it must be kept in mind that publicly produced knowledge may result in technology that is used by business while not inducing it to increase its research expenditure. Moreover, it is not the major purpose of government laboratories to produce knowledge for the business sector. For university research, barriers to the transfer of knowledge to business can be mitigated by government (targeted) funding of business R&D. And whereas the crowding-out effect is immediate (contemporaneous with the research spending), spillovers may take time to reach industry, beyond the horizon of the assessment.


This report analyzes international flows of human resources in science and technology, relying on the most recent data on policies and research performance assessments from OECD member and observer countries. The findings reported suggest that global innovation has increased as the international mobility of highly skilled workers has become more complex and frequent, and as more economies have come to participate in R&D and innovation activity. Consequently, competition for talent is now influencing innovation policy initiatives across the globe. The report recommends addressing shortcomings in national policies that may limit the domestic supply of skilled workers, and ensuring that the wider environment for innovation and scientific endeavor is sound.


This report documents the importance of research and recommends a number of steps to strengthen the U.S. research enterprise. It explains why, according to the classic public good argument, the federal government must fund basic research.
This report, requested by the Task Force on Science Policy of the House Committee on Science and Technology, explores whether the use of quantitative mechanisms associated with the concept of “investment” might allow for the meaningful prediction and measurement of research returns. The report concludes that while some quantitative techniques might prove useful to Congress in evaluating specific areas of research, basic science is not amenable to the type of economic analysis that might prove useful for applied research or product development. Even in the business community, the report concludes, decisions about research are much more the result of open communication followed by judgment than of quantification. The American research system endures and succeeds because it is complex and pluralistic, depending on various players (e.g., scientists, citizens, administrators, Congress) to reach final decisions on funding. Expert analysis, openness, experience, and expert judgment are better tools than economic quantitative methods, according to the report.

This report, prompted by the America COMPETES Act, finds that the competitiveness of the United States can be improved by focusing on three pillars that historically helped unleash the innovative potential of the private sector: federal support for basic research; education; and competitive, cutting-edge technological infrastructure (e.g., helping rural areas gain broadband Internet access). All three pillars are areas in which the federal government has made, and should continue to make, significant investments.
### d. Reference Technology Transfer Measurement Scheme Comparison

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Cornell University | Ball State Univ. | Humboldt State University | George Mason University |
Duke Univ. | Baylor College of Medicine | Indiana University | Georgia Institute of Technology All Campuses |
Emory Univ. | Boise State University | Northern Illinois University | Harvard University |
Harvard Univ. | Brandeis Univ. | Portland State University | Johns Hopkins University |
Johns Hopkins Univ. | Brown University | Prairie View A&M University | Michigan State University |
Louisiana State University System* | Carnegie Mellon Univ. | Southern Illinois University Carbondale | Ohio State University All Campuses |
Massachusetts Inst. of Technology (MIT) | Case Western Reserve Univ. | SUNY College of Environmental Science and Forestry | Purdue university |
Mount Sinai School of Medicine | Clemson Univ. | SUNY Fredonia College | Stanford University |
New York Univ. | Colorado School of Mines | The Ohio State University | University of Alabama |
North Carolina State Univ. | Colorado State Univ. | University of Alabama Birmingham Research Foundation | University of California, San Diego |
Northwestern Univ. | Creighton Univ. | University of Arkansas | University of California, San Francisco |
Princeton Univ. | Dartmouth College | University of Buffalo | University of Delaware |
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Stanford Univ. | East Carolina Univ. | University of Memphis | University of Michigan All Campuses |
Texas A&M Univ. System* | Florida State Univ. | University of Michigan | University of Minnesota All Campuses |
The Research Foundation for The State University of New York | Georgetown Univ. | University of Missouri | University of Pennsylvania |
The UAB Research Fdn. | Georgia Inst. of Technology | University of Oklahoma | University of Pittsburgh All Campuses |
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Univ. of Florida | Indiana Univ. Res. & Technology Corp.(IURTC) | University of Texas | University of Wisconsin–Madison |
Univ. of Georgia | Iowa State Univ. | University of Virginia | 18 |
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Vanderbilt Univ. | Northern Illinois University |       |
Washington University of St. Louis | Ohio State Univ. |       |
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Note: Universities in Italic overlap between the dissertation sample frame and the reference measurement scheme.

* 100% overlap with dissertation sample frame, only universities outside of sample frame included in column.

** Only the University belonging to either the top 25 universities by federal R&D expenditures (2011), top 25 campuses by total STEM graduates, and 7 initial pilot universities participating in STAR metrics are included. Universities were continuously enrolling throughout the Level 1 phase, and a complete list of level 1 institutions is no longer available since the transition to phase 2.
e. Reference Health Industry Report Evaluation

Reviewed PwC reference reports

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<td>Historically, pharma companies have marketed drugs to physicians who have been the primary drivers of patient drug adoption.</td>
<td>Increased price and quality transparency places pressure on drug manufacturers. Pharmaceutical companies must re-evaluate pricing models and develop new ways to add value, perhaps by partnering with new entrants targeting patients with relevant diseases or conditions.</td>
<td>Improve quality and impact of trials by gathering input from all relevant stakeholders.</td>
<td>Deploy new and innovative collaboration tools and platforms to innovate internal and external collaborations.</td>
<td>Capitalize on emerging mobile health apps and patient social networks to identify, recruit and retain patients during trials.</td>
<td>Leverage diagnostic devices, remote patient monitoring tools, and embedded microchips to re-invent clinical development.</td>
<td>Re-invent clinical systems by leveraging emerging technologies to streamline clinical processes (e.g., clinical supplies).</td>
<td>Improve trial insights, and outcomes by better integrating internal data with external real life data and leveraging the emergence of EMR/EMR.</td>
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<td><strong>Medical Device</strong></td>
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<td>In the past, medtech companies simply sold devices to consumers.</td>
<td>Now, the value of devices is no longer only in the actual product itself but also in how companies integrate information and services to solve larger problems.</td>
<td>Get closer to the user/customer by driving innovation at the speed of technology development and effectively integrating engineering, clinical, and user form and function input in the development cycle.</td>
<td>Provide systems and tools that allow multiple clinicians to access the same patient information.</td>
<td>Provide value beyond the device by integrating into a system of care or the life of the patient more closely through apps or integration with existing devices the patient uses.</td>
<td>Improve patient compliance and therapeutic adherence by leveraging technology to integrate therapists, devices and clinical care.</td>
<td>Remotely monitor patients through their devices.</td>
<td>Integrate device data with primary systems for comprehensive health management.</td>
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<td><strong>Provider (hospitals)</strong></td>
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<td>A largely local/regional industry with limited market influence / competitive pressure. More is better fee-for-service approach.</td>
<td>A &quot;new health economy&quot; that rewards value over volume. Managing health instead of treating disease.</td>
<td>Improve care quality and innovation by gathering input from caregivers at all levels of care delivery.</td>
<td>Better coordinate care transitions between different departments or care environments beyond the hospital walls.</td>
<td>Engage patients more actively in their health through social and mobile tools.</td>
<td>Use new data sources and meta analysis results data to support clinical decision making, value-driven evidence-based care.</td>
<td>Integrate diverse data sources to primary EHR systems to understand the person behind the patient.</td>
<td>Data pools to effectively develop meaningful information and refuse it into a system of care.</td>
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<td><strong>Payers (insurance)</strong></td>
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<td>Fee-for-service reimbursement Outcomes-based managed care</td>
<td>Patient satisfaction survey scores have begun to directly impact Medicare payment for health providers. California Healthcare Foundation, Consumer reports, Healthgrades, Leapfrog group, Vital, Yelp health ratings</td>
<td>Improve patient compliance and therapeutic adherence by leveraging technology to integrate therapists, devices and clinical care.</td>
<td>Engage patients more actively in their health through social and mobile tools.</td>
<td>Use new data sources and meta analysis results data to support clinical decision making, value-driven evidence-based care.</td>
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**Example:**
- **Medical Device:** Sanofi partners with pharmacy benefits manager Medco Health Solutions to get "real-world" insights into how different therapies compare when used in a clinical setting.
- **Pharma:** Roche Pharmacovigilance and Roche Diagnostics are working together on personalized medicine. Following a commitment by the chief executive officer to pass 80% of the company’s pipeline drugs with companion diagnostics.
- **Provider (hospitals):** Kaiser Permanente and the California Healthcare Foundation’s “Free the Data” Initiative. Leapfrog Group’s Hospital Safety Score.
f. Coding themes

Academia

A. Innovation creation
   • Publications, invention disclosures, patents (including challenges with using these as a metric); license agreements, and program revenue (including challenges with using this as a metric); metrics reflecting university’s mission, ethos of public service.

B. Knowledge acceleration and incubation
   • Incubation and acceleration program success, dollar value of sponsored research agreements or services provided, attraction of additional capital.

C. Collaborations
   • Alliances, research joint ventures, license revenue; industry relationships (material transfer agreements, consortia agreements, sponsored research, clinical trials, service to community), internal collaborations & sense of community, metrics for measuring collaborations, purpose of measuring collaborations.

D. Perspectives on and culture of applying metrics
   • Administration & support, cultural change on campus (curriculum changes, entrepreneurial dimensions as one factor in tenure decisions, popularity of entrepreneurship themes among students & faculty), significance of people & attitude.

E. Entrepreneurial focus
   • New products, new processes, start-up activity & no. of start-ups created, job creation, equity relationships, start-up survival.

F. Economic development
   • Developing local and regional workforce, regional innovation clusters, job creation.

G. Qualitative outcomes
   • Case studies, vignettes, new measurement categories, importance of measuring qualitative outcomes, stakeholder surveys & communication.

H. Key metric stakeholders
   • Students, alumni, funders, states/governors, rating agencies.

I. Impact of & pressure to undertake metrics
   • Challenges with metrics.
**Industry**

A. Emerging technology platforms
   - Open innovation, external stakeholder engagement/alignment, common goals with other sectors, product vs service model innovation.

B. Social, mobile and cloud technologies
   - Education, co-creation, business development/sales, problem solving and product servicing, R&D use.

C. R&D analytics
   - Big data (and challenges with), analytics, data sharing relationships.

D. New skill-sets
   - Human capital considerations.

E. Integration
   - Connecting core business systems with new technologies.

**Triangulation of results: universal coding scheme**

A. Innovation determinants
   - Technology push, market pull, coupling
   - Internal-external idea generation
   - Path-to-market pathways (inbound-outbound innovation)
   - Integration/parallel development
   - Communication & partnerships (inc. internally)
   - Market changes, understanding the market
   - Service value & relationship driven

B. Universal consensus metrics/measures
   - Input
   - Output
   - Outcome

C. Consensus measurement themes
   - Talented and interconnected workforce (accountability, integrity & communication; challenges with turnover, capacity & transferability; innovating new tech transfer models)
   - Adequate and dependable resources
   - World-class knowledge generation and diffusion

D. Socio-political factors
   - Regional differences, fragmentation.