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This dissertation examines, from an economic program evaluation perspective, North Carolina's Green Business Fund (the Fund), a state-level grants program to provide support for small businesses conducting R&D related to sustainability technologies. The evaluation of the Fund follows both traditional evaluation and statistical-based evaluation methodologies. The traditional economic evaluation herein presents an extension of an economic model that allows one to estimate the benefit-to-cost ratio of a program under the particular data-limitations that are present in this work. The results of the traditional evaluation suggest that the Fund resulted in a positive net social surplus. Specifically, if one assumes that the elasticities of demand for innovations developed by the Fund are similar to those in a competitive market, the benefit-to-cost ratio associated with the Fund is estimated to be greater than 2.0. To supplement the traditional evaluation methodologies, econometric analyses are conducted to examine the relationship between key program outcomes and firm- and project-characteristics. The findings from these analyses suggest that the roles of external investment and university partnerships are related to the creation of new jobs, the development of intellectual property, and the generation of revenues.

GOVERNMENT SUPPORT OF INNOVATION IN SMALL BUSINESSES:

NORTH CAROLINA'S GREEN BUSINESS FUND

by

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CHAPTER I

INTRODUCTION

> With careful management, new and emerging technologies offer enormous opportunities for raising productivity and living standards, for improving health, and for conserving the natural resource base.
>
> — United Nations (1987, p. 182)

The epigram, written over twenty-five years ago, expresses hope that technological advancements can improve the human condition while also enhancing environmental sustainability. While that might be possible, short-run concerns have spurred the implementation of national and international policies to address environmental sustainability issues, and many of those policies are complemented by attendant technology policies. Many of these policies support direct investments in research and development (R&D) toward technologies to mitigate the negative impacts of human activity on the environment. Such technologies are called sustainability technologies.[1]

This work examines North Carolina's Green Business Fund (the Fund), a state-level grants program to provide support for small businesses conducting R&D related to

[1] The benefits from implementing sustainability technologies can take many forms such as reductions in the costs of pollution abatement, mitigation of future negative impacts of environmental externalities, increases in energy efficiency, the development of new and non-polluting energy sources, and increased efficiency in the use of non-renewable resources. Sustainability technologies can even take the form of improvements in or the development of entirely new products or processes.

sustainability technologies. This initiative, and ones that are closely related in their focus and mechanisms, are hereafter referred to as sustainability technology (ST) programs.

Prior to an examination of the impacts and outcomes associated with the Fund, this work provides an overview of the relevant economic theory and historical background. Chapter 2 examines the economic theory relating to the markets for innovative activity, sustainability, and their overlap. This overlap is described as a "dual market" where inefficiencies in one half of the dual can impact the other half. (Jaffe, et al., 2010). Particular attention is paid to the methods through which government can intervene in these markets, and how the nature of the dual market impacts the efficacy of these interventions.

Chapter 3 provides additional background and context by examining U.S. innovative activity and sustainability policies. This background allows one to understand the policy environment present when the Fund was enacted. The Energy Independence and Security Act of 2008 is the federal policy most closely related to the Fund; both the Act and the Fund provide support for sustainability technology programs and indirectly support the creation of jobs in the environmentally friendly industries.

Government accountability and the effectiveness of policies are an important aspect of economic research. Chapter 4 explores the economic theory related to government intervention in markets, the potential for government to create inefficiencies, and motivates the need for careful analysis of government activity. Public funds are inherently costly; a cost that is borne by the tax-paying constituency. This inherent cost provides an impetus to examine and improve policies.

With the background context established and motivation for examination of government activities presented, Chapter 5 details the specifics of the Fund's operation and activities. In particular, this chapter provides insight into the selection process and describes the chosen projects. Further, Chapter 5 examines the adoption of similar ST programs in other states. The chapter presents an exploratory analysis of the determinants of adoption and provides potential explanations for the observed adoption patterns.

Chapter 6 overviews the relevant program evaluation literatures. Specifically, this chapter examines two bodies of literature: the traditional evaluation literature and the statistical-based program evaluation literature. Lessons are drawn from these literatures that focus on the critical decisions that researchers are forced to make when conducting an evaluation. These critical decisions include choosing the appropriate counterfactual, addressing endogeneity, attribution, and the appropriate benefits to include in the evaluation.

Chapter 7 overviews the survey instrument through which the North Carolina Board of Science and Technology gathered data about Fund participants. The survey questions are divided up into five broad categories. Each category is broken down into questions and sub-questions. This chapter describes each category and its questions, presents the responses to those questions, and provides insight into how these data may be used in the analyses.

The economic evaluation of the Fund follows both the traditional evaluation and statistical-based evaluation methodologies. Chapter 8 presents an extension of an economic model that allows one to estimate the benefit-to-cost ratio of a program under the particular data-limitations that are present in this work. The model herein, builds upon the previous work and provides an additional tool that researchers may draw upon to examine other programs. To supplement this evaluation of the Fund, econometric analyses are conducted to examine the relationship between key outcomes of interest and firm- and project-characteristics. Chapter 9 presents these statistical-based analyses, focusing on the outcome dimensions of job growth, the creation of intellectual property, and revenues.

Chapter 10 summarizes conclusions that can be drawn from this work. The evaluation conducted here suggests that the Fund resulted in a positive net social surplus. Specifically, if one assumes that the elasticity of demand for innovations developed by the Fund are similar to those in a very competitive market, the benefit-to-cost ratio associated with the Fund is estimated to be greater than 2. In addition to the net social surplus, this work examined the relationship between key outcomes of interest and firm- and project-characteristics. Findings here suggest that the roles of external investment and university partnerships are related to the creation of new jobs, the development of intellectual property, and the generation of revenues. Future policy makers can use both these observed relationships and the estimated surplus gains in their decisions to establish and refine similar programs.

CHAPTER II

GOVERNMENT'S ROLE IN THE MARKETS FOR INNOVATIVE ACTIVITY AND SUSTAINABILITY

Economists have examined the markets for innovation and sustainability for decades.[2] Their research provides a foundation on which one can base the rationale for government intervention in these markets. An overarching theme of this research is the existence of market inefficiency and the means through which government can attenuate these inefficiencies and their effects. This chapter provides an overview of the theory pertaining to government intervention in the market for innovation, sustainability, and their nexus. Popp (2012, p. 40-41) provided an informative description of the interaction between the technology and sustainability (which he describes as environmental) policy:

> Both technology and environmental policies play a role promoting green technologies. Environmental policies create demand for green technologies. However, without technology policy in place, insufficient incentives exist for creating and diffusing new technologies.

Specifically, this chapter overviews the role of government in the markets for innovation and sustainability, describes the interaction of market failures associated with

[2] The market for innovative activity parallels the "market for ideas" that Mokyr (2010, p. 38) described by stating: "The market for ideas is not a real market in the literal sense, but is a useful metaphor. In it, people with ideas and beliefs tried to sell them to others, acquiring influence and through it prestige. Just as commodity markets can be judge by their efficiency if they, for instance, observe the law of one price, we can define yardsticks for efficiency in the market for ideas."

both topics, and motivates the importance of government accountability. In the broader context of this dissertation, the goals of this chapter are to provide economic rationale for government intervention into the market for innovation and sustainability and to provide a lens through which to view the evolution of policy.

The remainder of this chapter is structured as follows. Section 2.1 discusses economic theory regarding the market for innovative activity, inefficiencies in this market, and potential solutions to these inefficiencies. Section 2.2 discusses economic theory related to sustainability issues, inefficiencies in the market for sustainability, and potential solutions to these inefficiencies. Section 2.3 discusses the dual market, the interaction of efficiencies in the two halves of the dual market, and solutions to these inefficiencies. Section 2.4 provides a summary of this chapter and notes how the theory presented herein can be used as a lens through which subsequent chapters may be viewed.

Innovative Activity

Researchers in the field of technological change and innovation have used different terms to describe the same concepts. Mansfield (1968, p.3) defined technological change as "the advance in knowledge relative to the industrial arts." Arrow (1962) described invention as the creation of knowledge. Hall and Rosenberg (2010) use the term innovation to encompass both technological change as well as other aspects of economic change.

This work will follow the description provided by Link (2012), which expressed the relationship between science, technology, and innovation as follows: science is the search for new knowledge, technology is the application of new knowledge, and innovation is the commercialization or use of technology. Innovative activity is defined here as the collection of creative activities that encompasses science, technology, and innovation. Relatedly, research and development (R&D) is an investment in innovative activity. The scope of R&D can range from basic research to applied research to development investments that seeks to bring knowledge to a market.

The remainder of this section provides an overview the economics of innovative activity. The section begins with a description of the benefits that come from these activities. It next describes the inefficiencies that arise in the market for innovative activity. This section concludes with a discussion of policy options available to the government to address these inefficiencies.

The Social Benefits of Innovative Activity

The impacts of innovative activity have been examined from both the microeconomic and the macroeconomic perspectives.

At a microeconomic level, innovative activity provides benefits to society via the creation of new processes and products, and bringing those products and processes to market. New processes may reduce the cost of production by improving efficiency and reducing the need for costly inputs such as capital, labor, and energy, and thus mitigate the negative externalities that they produce. New products may address consumers' wants and needs—leading to higher levels of utility—in ways that were previously impossible (e.g., the development of commercial airplanes as a faster means of travel). These cost reductions and utility enhancements have the potential to lead to increases in societal welfare.

At the macroeconomic level, economists have studied the impact of innovative activity on the creation of new inputs and processes leading to increased factor productivity. This relationship between new inputs and processes and increased productivity lead economists to associate technological change with economic growth.

Smith (1776/1937) provided the well-known example of the pin maker honing his craft and developing new processes for the creation of pins through the division and specialization of labor. One might consider Smith's pin-making advancement to be an example of a process innovation. Solow (1957), examining productivity growth in the United States, developed his foundational growth accounting model that attributed economic growth to technical change. Mansfield (1968, p.3) stated that technological change is "perhaps the most important factor responsible for economic growth." As described in Romer (2006), Romer (1990) contributed to "New Growth Theory" that expanded upon the work of Solow and included endogenous technological change as an important element to economic growth. Even more recently, when discussing long-term economic growth, Bernanke (2011, p.37) wrote:

> innovation and technological change are undoubtedly central to the growth process; over the past 200 years or so, innovation, technical advances, and investment in capital goods embodying new technologies have transformed economies around the world.

Inefficiencies Associated with Innovative Activity

Arrow (1962) was one of the first scholars to write on the subject of inefficiencies associated with market for innovative activity. He described three imperfections in the market for technology and innovation: indivisibility, inappropriability, and uncertainty.

Indivisibility and inappropriability are similar in that both are characterized by positive externalities. However, they differ in fundamental ways. One difference between indivisibility and inappropriability is who receives the benefits from these externalities. Winston (2006, p. 56) commented on this difference when he described indivisibility, which he called non-exclusivity: "an innovation generates positive spillovers to competitors," and inappropability, which he called nonappropriability: "an innovator is unable to fully capture profits from an innovation." These descriptions highlight another difference between inappropriability and indivisibility: the mechanism through which these spillovers occur. Indivisibility occurs because knowledge of an innovation is non-exclusive. That is to say, an innovative firm is unable to prevent competitors from gaining knowledge of and subsequently copying their innovation. Inappropriability occurs because firms are unable to charge a price for some portion of the benefits—to consumers, other firms, or society as a whole—stemming from the consumer's use of the innovation.

These positive spillovers and uncaptured profits lead to an underinvestment in innovative activity from a societal point of view as the decision maker is only concerned with private, and not social, benefits. Bernanke (2011, p. 38) described this phenomenon:

> If many people are able to exploit, or otherwise benefit from, research done by others, then the total or social return to research may be higher on average than the private return to those who bear the costs and risks of innovation. As a result, market forces will lead to underinvestment in R&D from society's perspective, providing a rationale for government intervention.

Two graphical representations of underinvestment in innovative activity (labeled here as R&D for ease of presentation) are shown in Figures 1 and 2. The first figure shows the divergence of marginal benefits of a given quantity of innovative activity between the agent and society.[3] The second figure shows underinvestment by considering the choice of a single firm to invest in competing innovative activity projects. The central theme in each figure is that inefficiencies lead to underinvestment in innovative activity and a loss of potential benefits to society. The difference between these representations hinges on whether investments in innovative activity are considered to be a continuous level of funding or the operation of discrete projects. Either conceptualization can be correct as economic agents may outlay funds for innovative activity as a lump sum or by individual projects.

[3] Economic agent is defined here to be an entity that is undertaking an economic activity (e.g., a firm that is investing in innovative activity).

Figure 1. Under Provision of R&D

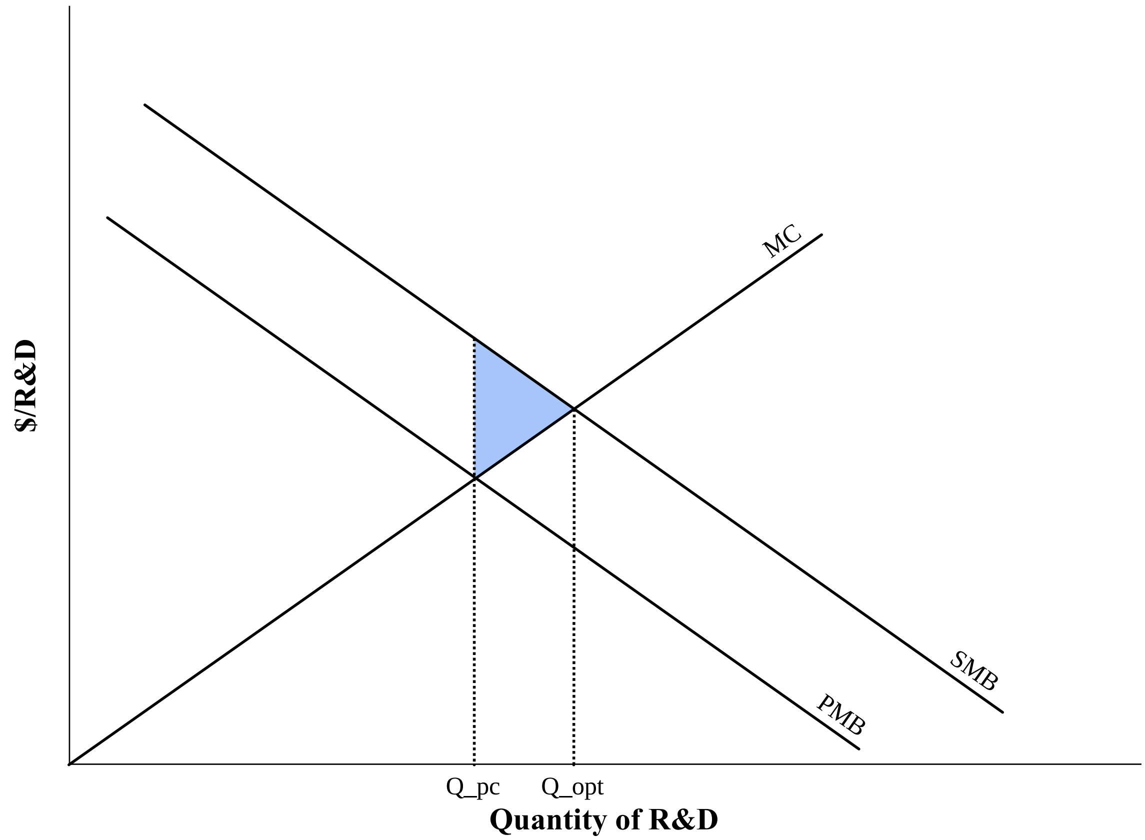

Figure 1 shows, for a representative firm, investment in innovative activity in terms social and private marginal benefits and marginal costs. The vertical axis measures both the benefit and cost of innovative activity in dollars-per-unit ($/R&D). The horizontal axis measures the quantity of innovative activity (Quantity of R&D).[4]

The line labeled MC depicts the relationship between a firm's chosen level of innovative activity (i.e., quantity of R&D) and the marginal cost of innovative activity at that level. The line labeled PMB depicts the private marginal benefits of a given quantity

[4] One may conceptualize the quantity of R&D as the number of labor hours directed towards innovative activity.

of R&D. These are the benefits that the firm is able to internalize through profits, reduced costs, or other mechanisms. The line labeled SMB depicts the social marginal benefits from a given quantity of R&D. These social benefits include both the benefits the firm is able to internalize and additional benefits the firm is unable to capture. Note that in Figure 1 the social marginal benefit is greater than the private marginal benefit for all levels of innovative activity. This relationship is due to the spillovers stemming from indivisibility and inappropriability associated with innovative activity. These spillovers are examples of positive externalities. Without public sector intervention, the firm will choose the perfectly competitive (pc) level of innovative activity that equates its marginal cost to its private marginal benefit; this quantity is shown as Q_pc. This level of innovative activity is lower than the level that would have been chosen by society. If society were to determine the level of innovative activity it would choose the level at which social marginal benefit. This is the socially optimal (opt) quantity as it results in maximum economic surplus. This socially optimal quantity is depicted as Q_opt.

The shaded region in Figure 1 represents the forgone economic surplus or deadweight loss. In this example, deadweight loss is the value of benefits forgone by society due to inefficiencies in the market for innovative activity. These inefficiencies are due to the imperfections in the market for innovative activity described by Arrow (1962) and lead to an underinvestment in R&D by the private sector relative to what is socially optimal.

Figure 2 provides a second illustration of underinvestment in innovative activity. This underinvestment stems from positive externalities associated with innovative activity creating a divergence in private and social rates of return. Link and Scott (2011a) provide a concise explanation that highlights the underinvestment in innovative activity. Link and Scott construct a model of firm decision making in which firms use hurdle rates to determine which innovative activity projects to pursue. A firm will *ex ante* evaluate an innovative activity project, and if the estimated rate of return is below some threshold level the firm will not invest in it. This threshold level is called the private hurdle rate. Analogous to the private hurdle rate, the social hurdle rate is the threshold rate of return to society above which projects are deemed worthwhile from a societal viewpoint. Because a firm is unable capture spillover benefits, the private rate of return can diverge from the social rate of return. This divergence combined with potentially differing hurdle rates between the firm and society can lead to private firms not investing in projects that are worthwhile to society.

As stated, Figure 2 illustrated underinvestment in innovative activity where investment occurs in a discrete (i.e., project-by-project) manner. The horizontal axis measures the private rate of return and the vertical axis measures the social rate of return. The dotted 45-degree line shows where the private rate of return is equal to the social rate of return. The solid lines show both the private hurdle rate (vertical solid line) and the social hurdle rate (horizontal solid line).

Figure 2. Private and Social Rates of Return

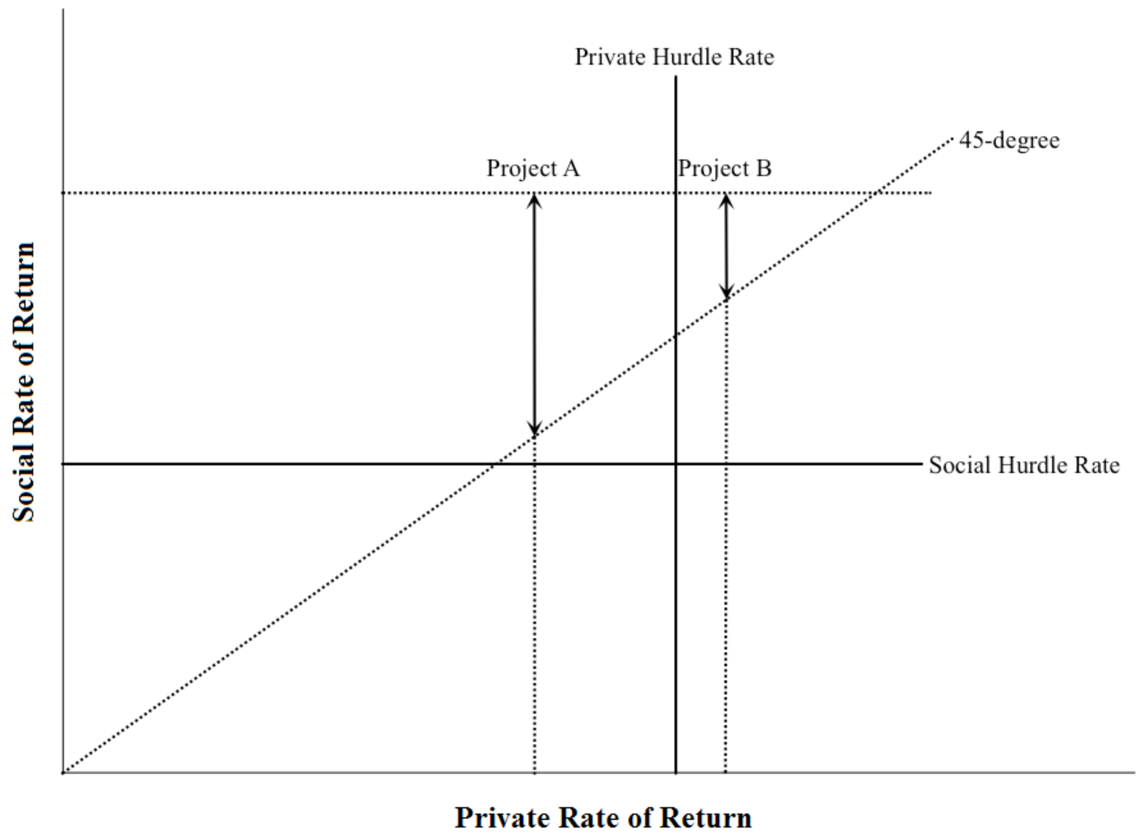

Figure 2 depicts two innovative activity projects, A and B. Both projects have the same social rate of return, which is above the social hurdle rate. Project A has a private rate of return that is below the private hurdle rate. Project B has a private rate of return that is above the private hurdle rate. The solid vertical lines with arrows indicate the spillover gap and measure the distance between the social and private rates of return. Project B will be undertaken by the firm while Project A will not, even though Project A is worthwhile to society (i.e., the social rate of return is above the social hurdle rate). If one considers the social hurdle rate to be the rate of return at which the net social surplus of a project is zero, then a rate of return above this hurdle rate reflects positive social surpluses. Given this consideration, a lack of investment in Project A reflects underinvestment—from society's view—in innovative activity.

To this point, this sub-section has focused primarily on the underinvestment in innovative activity caused by inappropriability stemming from spillovers. In addition to spillovers, uncertainty can lead to underinvestment in innovative activity.

Uncertainty in relation to innovative activity can occur through multiple channels including the R&D process and the market forces once innovation has brought the technology to market. Uncertainty in production, an inherent part of innovative activity, arises when the outputs of a production process are not certain when the input choices are made (Arrow, 1962). Hall et al. (2010, p. 1035) describe uncertainty of market forces after innovation when they noted that the return to R&D for the firm is dependent on "a complex interaction between firm strategy, competitor strategy, and a stochastic macroeconomic environment, much of which is unpredictable at the time a firm chooses its R&D program."

One may examine uncertainty using the framework of Figure 2. The return on an R&D project is not certain due to the factors outlined above. Thus, the rates of returns in Figure 2 are expectations. Firms that are more risk averse may place more emphasis on potential losses, leading to a lower expected rate of return for a project. If society is risk neutral, then the differences in risk preferences between the agent firm and society can cause a divergence between private and social rates of return. If this divergence is such that the social rate of return is greater than the hurdle rate but the private rate of return is below the hurdle rate, projects that should be funded—from society's point of view—will go unfunded, resulting in a market inefficiency.

Innovative Activity Policy Options

The government has several policy options to address the potential inefficiencies in the market for innovative activity. These options include: establishment and enforcement of intellectual property rights, investment in publicly performed innovative activity, and direct investment in privately performed innovative activity.[5]

The establishment and enforcement of intellectual property rights is a central role government plays in the market for innovative activity. These rights and their enforcement—through patents and copyrights—attenuate the effects of indivisibility by restricting the ability of competitors to appropriate the benefits of technological advances. These property rights allow firms to capture spillovers and mitigate positive externalities. There are, however, drawbacks to patents and copyrights including their restriction of future innovative activity and their limited effectiveness.

One may conceptualize the impacts of intellectually property rights through the framework of Figure 1. Without intellectual property rights, PMB represents the benefit of the innovative activity to the firm. As rights are established and increasingly strengthened, firms will be able to capture spillovers and the PMB curve will shift towards the SMB curve.

[5] The list of options provided here does not cover every possible option. However, the list does allow one to understand the goals and impacts of the specific policies to be discussed.

Publicly performed innovative activity is another policy option that the government may pursue. Publicly performed innovative activities alleviate market inefficiencies by aligning the preferences of the innovative agent and society. This alignment, in the framework of Figure 1, shifts the private marginal benefit curve to be equal to the social marginal benefit curve. In the framework of Figure 2, alignment of preferences results in an equalization between the private and public rates of return. In either framework the potential inefficiencies are mitigated, as the agent makes decisions based on the preferences of society.

Subsidization, or directly funding, privately performed innovative activity is another policy option that the government can employ to attenuate the imperfections in the market for innovative activity. Subsidization occurs when the government provides funds to private agents to perform activities, here innovative activities. The Fund, the focus of this work, is an example of subsidized innovative activities. Subsidies work to attenuate inefficiencies by reducing the cost of innovative activities.

One can conceptualize the impact of subsidies through the frameworks provided by Figure 1 and 2. Common to both conceptualizations is the idea that directly funding innovative activity reduces costs to the firm.

With regard to Figure 1, a per-unit subsidy reduces the marginal cost of the innovative activity, shifting the marginal cost curve downward. As the firm will choose to produce at the point where their marginal cost is equal to their private marginal benefit, this shift in the marginal cost curve increases the quantity of innovative activity produced. An optimally designed policy would move the marginal cost curve to the right so that the chosen level of innovative activity aligns with the socially optimal level, Q_opt.

With regard to Figure 2, direct funding reduces the investment cost of an innovative activity project but maintains the level of benefits from a project. This cost reduction increases the private rate of return for the project. To eliminate underinvestment, the government would subsidize innovative projects that have a private rate of return below the agent's private hurdle rate and a social rate of return that above society's hurdle rate (e.g., Project A). Optimally, this subsidization would shift the private rate of return to equal the private hurdle rate. This increase in the private rate of return would lead firms to invest in these socially optimal projects in which they would not previously invest.

Sustainability

In the last century, advances in understanding the effects of pollution on the environment and human health have strengthened concerns about sustainability and environmental externalities (Andrews, 1999). One may observe these advances through the evolution of environmental research from externalities caused by pollutants such as Dichlorodiphenyltrichloroethane (DDT) and sulfur dioxide (SO_2) to inter-temporal concerns over global warming caused by the release of greenhouse gasses into the atmosphere.[6]

[6] Dichlorodiphenyltrichloroethane (DDT) is an insecticide that is banned in the United States due to the unintended damage caused to wildlife by its use. Sulfur dioxide (SO_2) is a common product of fossil fuel combustion that can cause acid rain.

This section discusses the meaning and use of sustainability, describes the inefficiencies associated with the market for sustainability, and overviews some of the policy options that address these inefficiencies.

The Meaning and Use of Sustainability

Researchers and authors have defined and used several terms and ideas related to sustainability in their discussions of environmental, energy, and development policy. A commonly used term is "sustainable development." The *Report of World Commission on Environment and Development: Our Common Future,* issued by the Bruntland Commission for the United Nations (1987, p. 34), stated that: "sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future." Alternatively, In *Our Common Journey* the National Resource Council (1999, p. 22) defines the term sustainable development as "the reconciliation of society's developmental goals with its environmental limits over the long term."

Beyond providing a definition, efforts to describe sustainability related concepts have also discussed the "pillars" upon which sustainable development is built. The United Nations (2005) described the three pillars of sustainable development as: economic development, social development, and environmental protection. Focusing on energy rather than development, the American Council for an Energy-Efficient Economy (Prindle, et al., 2007) defined energy efficiency and renewable energy to be the "twin pillars" of sustainable energy policy.

The U.S. Environmental Protection Agency (EPA) shed some light on a possible definition for sustainability with the following statement (http://www.epa.gov/sustainability/basicinfo.htm):

> Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations

Following the description of sustainability provided by the EPA, sustainable is defined here to mean the allocation of resources in such a way that long-term environmental, energy, and natural resource use is feasible and that markets affected by environmental externalities achieve efficient outcomes in both present and future time periods. This is to say, the levels of resource consumption and pollution production do not: render the environment unable to support humanity and its activity, expend the available supply of energy and energy resources, deplete non-renewable resources without renewable alternatives, or create deadweight losses from environmental externalities. Sustainability policy is thus defined as those policies that either maintain or move towards sustainable outcomes.

These definitions highlight important aspects of sustainability and sustainability policy. First, they incorporate both static and inter-temporal elements. Second, they include the environment, energy, and natural resources into the definition due to their overlapping nature. This overlap may be observed through the production of energy, which often leads to the production of pollution and requires the consumption of non-renewable resources.

Environmental Externalities and Sustainability

One may begin consideration of the economic theory relating to sustainability by examining externalities in a static model. One may then extend the single-period model to an inter-temporal setting.[7] Externalities in a static model are costs or benefits that accrue to individuals other than the agent making the economic choice. Here, the externality considered is a negative externality where society bears the costs of pollution that the polluting agent does not face. This externality leads to an over-production of pollution from a societal standpoint.

Figure 3 illustrates a negative externality. The horizontal axis represents the quantity of a good that has a production process that creates pollution. The vertical axis measures the price of pollution. The line labeled PMC represents the private marginal cost faced by the producer of the pollution. The line labeled SMC represents the social marginal cost faced by society from the production of the pollution. The line labeled MB represents the marginal benefit of pollution. Without government intervention, producers will choose the perfectly competitive (pc) quantity (Q_pc). Note that at the quantity Q_pc, marginal benefit is lower than the social marginal cost. This means the costs to society outweigh the benefits. This results in a deadweight loss, represented by the shaded region. The socially optimal (opt) quantity of pollution is Q_opt, which is the

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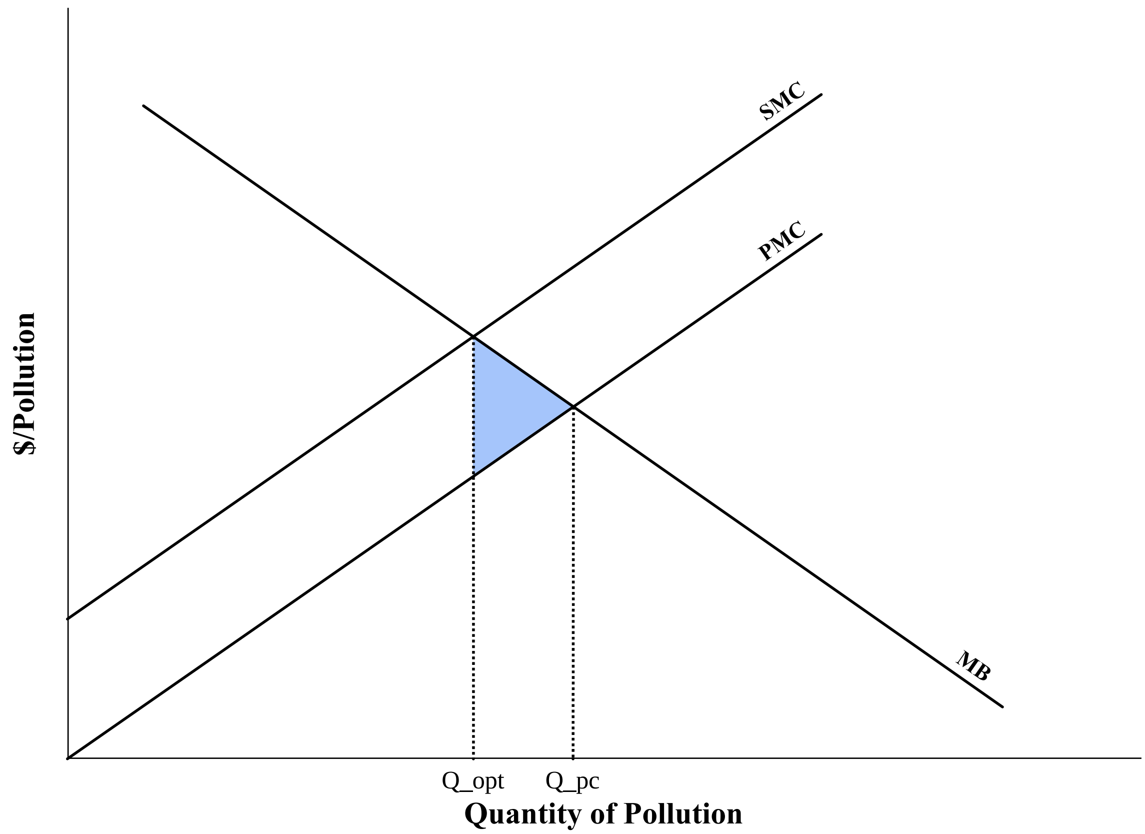
[7] Other topics associated environmental economics include natural resource usage and the impact of economic activity on the environment outside of pollution (i.e., stocks of wildlife).

quantity where social marginal benefit equals social marginal cost. Ideal government intervention would result in production at the socially optimal quantity.

Figure 3. Pollution Externality



One can extend the framework in by Figure 3 to an inter-temporal setting—moving it closer to the economics of sustainability as defined in the previous subsection. The addition of a time component to negative externality framework provides new mechanisms by which the private production and consumption can diverge from socially optimal quantities (e.g., discount rates and resource stocks). The depletion of non-renewable resources prevents their use by future generations.

Heal (1998, 2005) described the complexities inherent an inter-temporal framework and the optimal use of renewable resource stocks. Two types of externalities born by future generations arise: lagged pollution effects and divergences in discount rates between economic agents and society.

Climate change is an example of an inter-temporal externality and is of great concern to those who promote sustainability policies. Climate-change science suggests that increasing levels of greenhouse gasses released by human activity is leading to an increase in global temperatures. Increased global temperatures could increase the volatility of local weather patterns, cause polar ice to melt and raise sea levels, and lead to sustained weather events such as droughts, and food shortages. As present time agents impose these future negative effects, climate change is an example of an inter-temporal externality.

Sustainability Policy Options

The goal of sustainability policy is to incentivize sustainable resource allocation and eliminate inter-temporal externalities. The government may implement policies that are designed to impact the static framework, the inter-temporal framework, or both.

Remedies to the static externalities caused by pollution may use a range of mechanisms. The simplest solution is to ban a form of pollution.[8] One policy mechanism is to impose a quantity cap on certain pollutants, issuing permits for its release, and establish a market for pollution permits. This option allows for some positive amount of

[8] Banning pollution ignores the possibility that some positive quantity of pollution is socially optimal, as shown in Figure 3.

pollution and given proper valuation and controls may provide an efficient outcome. That is to say, the marginal benefits of pollution to society will equal the marginal costs of that pollution. Another policy mechanism is a tax on the production pollution. Properly calibrated, a per-unit tax on pollution shifts the private marginal cost (PMC) curve in Figure 3 so that it aligns with the social marginal cost.

Similarly, the government may enact policies to address inter-temporal sustainability concerns. The mechanisms through which government acts are similar to those in a stats model but now are calibrated to consider future time periods. The focus of these policies when facing inter-temporal externalities and discount-rate differences is to bring consumption of non-renewable resources and the production of long-term pollutants to their optimal quantities. As with the static case, the government may employ both quantity and pecuniary policy mechanisms to achieve these goals.

The Dual Market

Jaffe and Newell (2005) and Popp, et al. (2010) presented the dual market concept, a representation of the interaction between the market inefficiencies related to technology and environmental externalities. Here, the dual market concept considers the inefficiencies related to interaction between the markets for innovative activity and sustainability. The authors note the back-and-forth interactions between the two halves of the dual market (Jaffe and Newell, 2005, p. 164):

> New technology has been credited with solving environmental problems by mitigating the effects of pollutants, and has been maligned as a source of increased pollution.

This section describes the economics of the dual market between innovative activity and sustainability, and is structured as follows. First, the section discusses the potential for innovative activity to reduce the impact of inefficiencies in the sustainability market and for policies promoting sustainability to induce innovative activity. Second, the section describes the relationship between inefficiencies in one market can compound inefficiencies in the other market. Third and finally, the section addresses policy options that affect innovative activity and sustainability.

Sustainability Innovation

Central to the relationship between innovative activity and sustainability is the concept of sustainability innovation, which serves as a link between the two halves of the dual market. Here, sustainability innovation describes the development and commercialization of technologies that reduce environmental externalities, improve energy-efficiency, or otherwise enhance sustainability.

Sustainability innovation can take the form of changes to technologies that are in use or the creation and commercialization of entirely new technologies. These new technologies can come in the form of products, services, or processes. The benefits from sustainability innovations can take many forms such as: reductions in the costs of pollution abatement, mitigation of future negative impacts of environmental externalities, increases in energy efficiency, development of new and non-polluting energy sources, and increases in the efficiency of non-renewable resource usage.

Complementary Solutions

The concept of complementary solutions in the dual market framework refers to the potential for innovative activity to reduce inefficiencies in the market for sustainability and for policies promoting sustainability to reduce inefficiencies in the market for innovative activity. The market for innovative activity can reduce inefficiencies in the market sustainability through the development of sustainability innovations. Sustainability efforts can induce innovative activity by providing incentives for firms to invest in innovative activity towards sustainability innovations.

The development of sustainability innovations can mitigate the inefficiencies in the market for sustainability in several ways, including: reducing the quantity of harmful pollution for a given level of production, decreasing the social cost of pollution, and creating renewable alternatives to non-renewable resources. Innovations that provide a reduction in the level of pollution for a given level of output include: flue-gas desulfurization systems (i.e., scrubbers), green building materials and processes, and catalytic converters. Some examples of innovations that decrease the social cost of pollution are: open-air carbon capture and sequestration, toxic material removal systems (e.g., water purification systems). Sustainability innovations in the field of renewable resources include: biofuels and other alternative energy sources, recycled materials and recycling techniques, and renewable building materials (e.g., sustainably grown bamboo).

Government intervention in the market for sustainability can lead to increased investment in the market for innovative activity. For example, implementing policies that require firms to reduce their pollution output can incentivize investment in sustainability innovations. Thus, using environmental policies to increase the demand for environmental innovation is a complementary solution to the inefficiencies in the market for innovative activity. In particular, increases in demand for sustainability innovation can reduce some of the uncertainty of investments in innovative activity that are related to the potential size of the end-product market.

Compounding Failures

Jaffe, et al. (2005) and Popp, et al. (2010) examined the interactions of market inefficiencies that arise from the dual market. The market inefficiencies in the market for sustainability lead to reduced demand and higher uncertainty in the market for innovative activity directed towards sustainability innovation. Meanwhile, the inefficiencies in the market for innovative activity reduce the incentives for firms to invest in the development of sustainability innovations that could mitigate inefficiencies in the market for sustainability. Jaffe et al. (p.165) expressed this idea as: “The problem compounds because independent of the externality associated with pollution, innovation and diffusion are both characterized by externalities as well as other market failures.”

This compounding can be understood by considering the demand for sustainability innovations. In the absence of government intervention, there is no incentive to mitigate the effects of negative environmental externalities because costs are not borne by the externality-creating economic agents. This lack of incentive leads to limited demand for sustainability innovations, thus reducing the expected returns on R&D projects in these fields. Reductions in expected returns combined with the inefficiencies inherent with the market innovative activity, the level of investment in sustainability innovation is reduced below already sub-optimal levels.

Government's Role in the Dual Market

Government's role in the dual market is to remove the barriers that bring about market inefficiencies. When facing the dual set of inefficiencies associated with innovative activity and sustainability, government can choose among several approaches to influence the markets. Government can address each market individually, address the dual-market jointly, or use a combination of policies that both address each market individually and the dual market as a whole.

Addressing only one half of the dual market leaves the potential for inefficiencies in the other half to persist, mitigating the impact of these efforts. For example, if government choses to only address the market for innovative activity, a lack of demand can prevent diffusion and adoption of sustainability innovations. Alternatively, addressing only the market for sustainability neglects the spillovers and uncertainty inherent in the market for innovative activity.

Alternatively to addressing each market individually, the government might address the dual market by incentivizing investments in sustainability innovation directly. Targeting the dual-market ensures that neither side of the market failure is left wanting for policy remedies, although the effect may be muted without policies that address inefficiencies inherent in each individual market. Policy options that incentivize environmental innovation directly include: direct investment (i.e., grants and funds programs), public procurement, and tax credits.

Government can also choose to use a mix of policies that address both markets independently and the dual market as a whole. Jaffe, et al. (2005) and Popp, et al. (2010) all discuss the efficiency of policy design and mix for addressing the dual market. Jaffe, et al. stated that (2005, p.173):

> for cases in which private incentives do not reflect the full costs of environmental externalities, for whatever reason, the efficiency of the policy mix will likely be improved by including public policies aimed directly at stimulating the development and diffusion of new environmentally benign technology.

Popp, et al. overviewed the literature on the relative efficiency of addressing the two sides of the dual market either individually or jointly. They concluded that the most effective means of addressing the barriers to environmental innovation is a portfolio of initiatives that include policies for each market individually as well as policies that span both sides of the dual market.

Summary

This chapter examined the economics of innovative activity, sustainability, and the interaction of inefficiencies between the markets for each. The market for innovative activity, including science, invention, and innovation, provides a source of growth for the economy, but comes with the imperfections of inappropriability, indivisibility, and uncertainty. The market for sustainability, including environmental protection, preservation of natural resource stocks, and energy efficiency efforts, in effort to establish feasible long-run consumption and minimize negative externalities in both static and inter-temporal settings. Combined, these markets form a dual market where inefficiencies in either half compound, but efforts in one half may mitigate inefficiencies in the other.

Chapter 3 draws on the discussion presented in this chapter to overview the history of U.S. policies related to innovative activity and sustainability.

CHAPTER III

U.S. INNOVATIVE ACTIVITY AND SUSTAINABILITY POLICIES

Public policies have shaped the markets for innovative activity and sustainability in the United States. These policies have a wide range of purposes and mechanisms through which they influence markets. Drawing on the discussion of the dual market from the previous chapter, one can divide these policies into three categories: those that directly influence only innovative activity, those that directly influence only sustainability, and those that influence both halves of the dual market. This chapter overviews relevant policies in each category through the lens of the theory in Chapter 2.[9] After overviewing the relevant policies, this chapter discusses the policy environment in which the NC Green Business Fund was created.

U.S. Innovative Activity Policies

The U.S. government has enacted a range of policies affecting the market for innovative activity. These policies have targeted the economic inefficiencies described in Chapter 2 using a range of mechanisms. This section provides an overview of the recent history of technology and innovation policy in the United States.

[9] This policy review focuses primarily on Congressional legislation, but it includes some discussion of executive actions and other initiatives. An overview of state-level programs similar to the Fund is provided in Chapter 5.

Table 1 lists recent policies that have directly influenced the market for innovative activity in the United States. The table provides the policy name, the year it was enacted, and a description of its purpose and effects.

Table 1. Recent U.S. Innovative Activity Policies

Policy Name	Year	Purpose and Effects
Inclusion of R&D into Tax Code	1957	Allows for firms to expense R&D expenses like other costs.
Bayh-Dole Act of 1980 (PL 96-517)	1980	The Bayh-Dole Act allowed individuals at universities and small businesses conducting federally funded research to retain sole patent rights.
Stevenson-Wydler Technology Innovation Act (PL 96-480)	1980	The Stevenson-Wydler Act allowed federal laboratories to retain intellectual property rights stemming directly from their work
Economic Recovery Tax Act of 1981 (PL 97-34)	1981	The R&E tax credit provided a tax credit on pre-competitive research expenditures.
Federal Courts Improvement Act of 1982 (PL 97-164)	1982	The Federal Courts Improvement Act reorganized the federal court system and created the Court of Appeals for the Federal Circuit and the Claims Court, establishing a more uniform and consistent application of patent law.
Small Business Innovation Development Act of 1982 (PL 97-219)	1982	The SBIR program required that federal agencies with large research budgets allocate a small percentage of their extramural research funds to projects that are conducted by small businesses.

Policy Name	Year	Purpose and Effects
National Cooperative Research Act of 1984 (PL 98-462)	1984	The NCRA, and its subsequent amendments, promoted collaborative research between competitive firms. It changed rules regarding anti-trust regulation to allow joint research and development ventures.
Federal Technology Transfer Act of 1986 (PL 99-502)	1986	The Federal Technology Transfer Act required that researchers at federal laboratories receive a portion of the royalties from inventions they developed while employed at the federal lab.
Biomass Research and Development Act of 2000 (PL 106-224)	2000	The Biomass R&D Act provided support for research and innovation in the field of biofuels and other bio-based products.
21st Century Nanotechnology Research and Development Act (PL 108-153)	2003	The Nanotechnology R&D Act provided support for research into nanotechnologies. A variety of initiatives were established and funding through various federal agencies was authorized.
America COMPETES Act of 2007 (PL 110-69)	2007	The America COMPETES Act focused heavily on STEM education and called for reports on the state of science research and competitiveness in the United States.
America COMPETES Reauthorization Act of 2010 (PL 111-358)	2010	In 2010 the America COMPETES act was reauthorized with increased levels of funding for the National Science Foundation, STEM education and other areas. Additional to funding, this act included provisions to increase the efficiency and cooperation of R&D across agencies.

Policy Name	Year	Purpose and Effects
Leahy-Smith America Invents Act (PL 112-29)	2011	The Leahy-Smith America Invents Act provided support for the U.S. Patent and Trademark Office to decrease the average patent approval time, increase the quality of patents and provide alternatives to litigation in court for inventors who have the legality of their patents challenged.

One may observe that the majority of the policies listed in Table 1 were enacted in the first half of the 1980's. These policies reflect attempts to address the productivity slowdown of the 1970's. (Link, 2012)

Legislative initiatives designed to increase the general level of investment in innovative activity in the United States have been few in number. Changes to the federal tax code in regards to research expenditures and the Research and Experimentation (R&E) Tax Credit are the two policy actions that fall into this category. In 1957 Congress changed the federal tax code to allow firms to expense R&D costs the same as other costs. (International Tax Centre, 1990) The R&E tax credit, enacted as the Economic Recovery Tax Act of 1981, provides a tax credit on pre-competitive research expenditures. Congress has acted to renew the R&E tax credit many times since it was first established, but has not made it permanent. The R&E credit is an incremental credit, meaning it applies only to increases in R&E expenditures over a defined base level. This means it provides incentives for firms to increase their level of pre-competitive research and experimentation beyond the established base. The addition of R&D expensing to the tax code and the R&E tax credit are broad policies that affect a wide range of firms investing in innovative activity. In relation to the economic theory discussed in Chapter

2, the R&E tax credit reduces the marginal cost of increased innovative activity levels, which incentivizes higher levels of investment in these activities.

In addition to Economic Recovery Tax Act of 1981, the government also enacted policies designed to increase the rate of technology transfer and commercialization. The Bayh-Dole Act of 1980 and the Stevenson-Wydler Technology Transfer Act of 1980 incentivized the transfer of technology transfer from federally funded research conducted at universities, small firms, and federal research laboratories to the private sector. The Federal Technology Transfer Act of 1986 provided incentives for researchers at federal laboratories to transfer technology to the private sector by requiring that they receive at least 15 percent of the royalties from patents stemming directly from their work.

Prior to these three acts, property rights of technologies developed from federally funded research belonged to the federal government. After the enactment of these policies, federal researchers could appropriate these rights and thus capture the economic benefits.

One can view the Bayh-Dole Act, the Stevenson-Wydler Act, and the Federal Technology Transfer Act through the framework illustrated in Figure 1. Prior to these policies, researchers were unable to capture the full marginal benefits of their research because the intellectual property rights of their inventions belonged to the federal government. That is, there was a divide between the researchers' private marginal benefit and social marginal benefit. By assigning property rights, these policies allowed researchers to capture the external marginal benefits of their innovation. This assignment of property rights shifted the researchers' private marginal benefit curve to align with the social marginal benefit curve, thereby eliminating the deadweight loss.

The National Cooperative Research Act (NCRA) of 1984 allowed firms to enter a research join ventures (RJVs). An important incentive of the Act is that realized, not treble, damages could be imposed in the event of antitrust litigation. This act requires firms wishing to enter into a RJV to file their intention with the Department of Justice.

Research cooperation between firms, which decreases redundancy in research,, has the effect of reducing the investment cost to an individual firm. This cost reduction increases the private rate of return to a research project, and potentially leads to investment in innovative activity projects that are socially worthwhile but would have not otherwise been made.

The Federal Courts Improvement Act of 1982 and the Leahy-Smith America Invents Act changed aspects of U.S. patent law. Both initiatives were designed to improve the patent-litigation process. The Federal Courts Improvement Act of 1982 established the Court of Appeals of the Federal Circuit and the Claims Court to handle matters related to patent litigation. The goal of this act was to establish more uniform application of patent law in the legal process; thus, reducing uncertainty related to innovative activity. The Leahy-Smith American Invents Act changed the litigation process by allowing for less-costly litigation alternatives and increasing the speed of patent approval. These laws increased the return on investments in innovative activity by mitigating uncertainty about the ability of firms to appropriate benefits from their efforts, reducing litigation costs, improving the litigation process, and increasing the speed of patent approval.

In spite of concern in the 1990s that America was losing its competitive advantage in terms of research, science and technology (National Resource Council, 1999), there was a lack of new innovative activity policies enacted between the late 1980s and the early 2000s. One can divide innovative activity policy in the 2000s into two groups: the first group targets specific scientific fields, and the second group incentivizes research in a broad range of fields especially science, technology, mathematics, and engineering (STEM) education.

In the early 2000s, innovative activity policies, including the 21st Century Nanotechnology Research & Development Act and the Biomass R&D Act of 2000, targeted specific scientific fields. In 2007 and 2011 Congress passed the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act and its reauthorization, both of which promoted general research and STEM education.

The 21st Century Nanotechnology R&D Act's purpose was to advance the state of nanotechnology and related production processes. This act provided funds for research, established public-private partnerships, and directed funds through federal agencies for agency goal specific research. Fundamental aspects of the act included: promotion of basic research in the nanotechnology field, the creation of interdisciplinary nanotechnology research centers, and public-private cooperation. These efforts increased the private rate of return on projects by reducing the cost of innovative activity investment and allowing firms to reduce uncertainty via joint projects with the government.

The Biomass R&D Act promoted the development and growth of the biomass industry in the United States. The Biomass R&D Act allocated funds for the development of new biomass products, designing and building biomass refineries, and other related activities. This act also established funding programs to support the development of new bio-stocks, the development of new bio-based products, and advances in the production system through both the creation and enhancement of new and existing methods and processes. Through direct funding, this act increased the private rate of return on innovation in the biofuel industry by reducing the cost of innovative activity projects.

One can conceptualize the impact of the 21st Century Nanotechnology R&D Act and the Biomass R&D Act through the framework of Figure 2. Both policies contained provisions that established programs to provide direct funding to qualifying innovative activity projects. These programs provided funds for innovative activity to develop either particular innovations or answer narrowly defined questions. Funding decisions for these programs were based on the potential benefits of the proposed projects. Ideally, agencies operating these programs would *ex ante* evaluate projects and provide funds to those that were expected to yield social rates of return above the social hurdle rate and private rates of return below the private hurdle rate (i.e., Project A in Figure 2).

Congress passed the America COMPETES Act of 2007 in an attempt to address the loss of the United States' research advantage by providing funds for both STEM education and for innovative activity in a broad range of areas. Congress later passed the

America COMPETES Reauthorization Act of 2010 with even higher levels of funding and expanded support. In addition to increased funding, the America COMPETES Reauthorization Act of 2010 included provisions such as the creation of the Committee on Technology to increase the efficiency and cooperation of R&D across agencies. The America COMPETES Act and its reauthorization appeal to economic theory related to innovation through two mechanisms: first, reducing the cost of human capital development through STEM education funding; and second, subsidizing research activities, which reduces innovative activity costs and increases the private rates of return.

U.S. Sustainability Policies

The U.S. Environmental Protection Agency (EPA, 2013) stated:

> In the United States, the first establishment of a national policy for environmental sustainability came in 1969 with the passage of the National Environmental Policy Act of 1969 (NEPA) whose purpose was to "foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony and fulfill the social, economic and other requirements of present and future generations."

The two decades following the establishment of NEPA saw the passage of many foundational sustainability policies. This section surveys the history of sustainability policy in the United States, and examines these policies through the lens of economic theory.

Table 2 provides a timeline of environmental and sustainability legislation in the United States. It lists the policy, the year of enactment, and a brief summary of the legislation's purpose. Following the definition of sustainability in Chapter 2, Table 2 includes policies that target the environment, energy, and natural resources. One may observe that half of the policies listed were enacted in the years 1969 through 1980. The legislation of this period set the foundation of U.S. environmental and sustainability policies. This observation provides some insight as to why the 1970s have been called the environmental decade.[10]

Table 2. U.S. Sustainability Policies

Policy	Year	Summary
National Environmental Policy Act of 1969 (PL 91-190)	1969	The National Environmental Policy Act of 1969 requires federal agencies to conduct various levels of analysis to determine if planned actions potentially impact the environment. In addition to impact studies, NEPA established the Council on Environmental Quality. (Council on Environmental Quality, 2012)
Creation of the Environmental Protection Agency (EPA) (Reorganization Plan no. 3 of 1970)	1970	The EPA has a wide range of responsibilities: establishing and enforcing regulation, enforcing federal laws protecting health and the environment, provide the public with information regarding health and environmental issues, and to conduct research on regarding environmental and public health issues. (EPA, 2012i)

[10] For further discussion of the environmental decade and environmental policy before 1969, see Andrews (1999).

Policy	Year	Summary
Clean Air Act Amendments of 1970 (PL 91-604)	1970	The Clean Air Act was originally passed in 1963 but was amended in 1970 to provide for stronger regulation and enforcement. The 1970 Clean Air Act Amendments established the National Ambient Air Quality Standards, New Source Performance Standards and National Emissions Standards for Hazardous Air Pollutants. (EPA, 2007, 2012f)
Federal Water Pollution Control Amendments of 1972 (Clean Water Act) (PL 92-500)	1972	The Federal Water Pollution Control Amendments of 1972 established pollution control programs, standards for surface water contaminants, and required that a permit be obtained before dumping pollutants into navigable waters from a point source.
Safe Drinking Water Act (PL 93-523)	1974	SDWA established standards to protect the public from potentially harmful contaminants in tap water and required that public water systems meet these standards. (EPA, 2012c)
Energy Policy and Conservation Act (PL 94-163)	1975	The EPCA, among other things, led to the creation of the Strategic Petroleum Reserve and to the creation of corporate average fuel economy (CAFE) standards for vehicles. (National Highway Transportation Safety Administration, 2002)
Toxic Substances Control Act (PL 94-469)	1976	The TSCA provided the EPA with the ability to oversee toxic chemicals and mixtures. Specifically, the EPA can require reporting, testing, and compliance with established regulation. (EPA, 2012e)
Resource Conservation and Recovery Act (PL 94-580)	1976	The Resource Conservation and Recovery Act provides the EPA with oversight of hazardous waste through all stages of its lifecycle: production, usage, transportation and disposal. (EPA, 2012b)

Policy	Year	Summary
Department of Energy Reorganization Act (PL 95-91)	1977	The Department of Energy Reorganization Act created the Department of Energy. It combined the roles of the Energy Research and Development Administration, the Federal Energy Administration and the Federal Power Commission.
Clean Water Act of 1977 (PL 95-217)	1977	The CWA Amendments of 1977 enhanced the EPA's control over the regulation established in the CWA. It also established the requirements that certain best practices and technology standards be adopted regarding water pollution control. (LawBrain, 2012)
National Energy Conservation Policy Act (PL 95-619)	1978	The NECPA contained multiple component acts designed to reduce American energy consumption. Notably, the Energy Tax Act created the gas-guzzler tax that levied taxes on vehicles that did not meet certain fuel efficiency standards as well as provided tax credits for individuals who installed renewable energy systems.
Energy Security Act (PL 96-294)	1980	Contained six component acts. This act targeted renewable and environmentally friendly energy areas with the goal of reducing dependence on foreign oil.
Comprehensive Environmental Response Compensation and Liability Act (Superfund) (PL 96-510)	1980	Congress established the Superfund for use by the EPA to clean up orphaned toxic waste sites. The EPA is able to force responsible parties to participate in the cleanup process through a variety of mechanisms and can hold responsible parties financially accountable. (EPA, 2012d)
Water Quality Act of 1987 (PL 100-4)	1987	The WQA enhanced the CWA in regards to water quality standards and required that states adopt numeric criteria for certain water pollutants with regard to water quality. It also allowed the EPA to work with Native American tribal regions to administer the CWA (EPA, 2012g)

Policy	Year	Summary
Alternative Motor Fuels Act (AMFA) (PL 100-494)	1988	The Alternative Motor Fuels Act added provisions to the established CAFE standards to promote alternative fuel. In addition to changes to CAFE, the AMFA directed that studies to examine the use of alternative fuels to power trucks and buses. (National Highway Transportation Safety Administration, 2002)
Oil Pollution Act of 1990 (PL 101-380)	1990	Congress passed the Oil Pollution Act of 1990 in response to the Exxon-Valdez oil spill. It contained provisions regarding the clean-up and payment of damages caused by oil spills, enhanced regulation for off-shore oil drilling and the transportation of oil, and a fund was created to provide resources for cleanup in case of future spills.
Clean Air Act Amendments of 1990 (PL 101-549)	1990	The Clean Air Act Amendments of 1990 established standards for a broader range of pollutants and imposed a permit system for stationary sources. Perhaps most well-known, these amendments included Title IV, which created the SO_2 cap and trade program. (EPA, 2007)
Energy Policy Act of 1992 (PL 102-486)	1992	The Energy Policy Act of 1992 centered on the energy use and energy efficiency of the federal government. Agencies were required to meet standards regarding energy-efficiency of their buildings, vehicles fleets and equipment.
Executive Order 13221	2001	Executive Order 13221 required Federal agencies to purchase electronics that meet stringent standby-power requirements or the next best alternative. This requirement is contingent on the product in question being practical when considering life-cycle cost and assigns the DOE to establish the final list of products that meet this requirement. (Department of Energy, 2009)
Energy Policy Act of 2005 (PL 109-58)	2005	An expansion of the Energy Policy Act of 1992, this act provided incentives for energy-efficiency, renewable energy production and included a change to daylight savings time.

Policy	Year	Summary
Energy Independence and Security Act of 2007 (EISA) (PL 101-140)	2007	The Energy Independence and Security Act of 2007 took action to reduce energy consumption and increase domestic energy production. To accomplish these goals EISA provided support for R&D programs, strengthened CAFE standards, imposed new requirements on federal agencies regarding vehicle and building energy-efficiency standards, and other measures.
Executive Order 13423	2007	Executive Order 13423 established an array of goals regarding energy efficiency, conservation and environmental impacts that Federal agencies were required to meet. The specific goals set forth covered a broad spectrum of areas including: greenhouse gas emissions, renewable energy consumption, water consumption, the energy efficiency of agency electronics, the amount of toxic chemicals used, the efficiency of buildings the agency owns, and the petroleum usage of the agency's fleet of vehicles. (EPA, 2012j)
Energy Improvement and Extension Act of 2008 (EIEA) (PL 110-343)	2008	The Energy Improvement and Extension Act of 2008 (EIEA) continued and enhanced support for sustainable energy initiatives. EIEA had four major titles: Energy Production Incentives, Transportation and Domestic Fuel Security Provisions, Energy Conservation and Efficiency Provisions and Revenue Provisions.
American Recovery and Reinvestment Act of 2009 (ARRA) (PL 111-5)	2009	The American Recovery and Reinvestment Act of 2009 contained many provisions regarding environmental and sustainability policy. The ARRA provided funds for green building innovation and production, investment in the development of renewable-energy sources, and a wide range of renewable energy and energy-efficiency projects. (DOE, 2012a) (EPA, 2012a)
Executive Order 13514	2009	Executive Order 13514 builds upon previous orders, enhancing the Federal government's energy management protocols and increasing support for energy-efficiency. It requires that agencies assign a Senior Sustainability Officer, establish a strategic sustainability performance plan, and make efforts to improve the sustainability of their buildings. (EPA, 2012k) (DOE, 2012b)

The main thrust of sustainability policy in the 1970s was the mitigation of negative environmental externalities through the establishment of laws, regulations, and enforcement mechanisms. Additionally, efforts to improve the coordination of sustainability policy creation and enforcement included the creation of the Environmental Protection Agency (EPA) and the Department of Energy (DOE).

As expressed by the EPA, one can consider the passage of NEPA in 1969 the start of sustainability policy in the United States. NEPA requires federal agencies to conduct *ex ante* analyses to determine if planned actions potentially impact the environment (Council on Environmental Quality, 2012). There are two levels of such analyses: an environmental assessment (EA) or an environmental impact statement (EIS). Alternative to an EA or EIS, agencies may apply for a categorical exception. In addition to impact studies, NEPA established the Council on Environmental Quality to coordinate federal environmental efforts and to provide advice on environmental policy. NEPA reflects an understanding by the government that externalities should be considered, but is not a remedy in its own right.

President Richard Nixon established the EPA in 1970 as a reorganization of the executive branch of the federal government. (EPA, 2012i) The EPA combined parts of other agencies with responsibilities to protect public health and the environment. The EPA has the responsibility to establish and enforce U.S. sustainability policy. This responsibility includes enforcement of many of the laws listed in Table 2. The EPA also promotes sustainability efforts through means other than regulation enforcement. One recent effort was the creation of the ENERGY STAR labeling program, which promotes the production and usage of energy-efficient electronics.

The Clean Air Act Amendments of 1970 established the National Ambient Air Quality Standards (NAAQS), New Source Performance Review, and National Emissions Standards for Hazardous Air Pollutants. (EPA, 2007, 2012f) NAAQS required the EPA to establish and enforce standards for: CO (carbon monoxide), NO_2 (nitrogen dioxide), SO_2, particulate matter, hydrocarbons and photochemical oxidants (nitrogen oxides and volatile organic compounds). NAAQS categorizes regions that failed to meet the standards as "non-attainment areas," and those regions that do meet the standards as "attainment areas." Further, NAAQS require non-attainment areas to take measures to reduce emissions.

The Federal Water Pollution Control Amendments of 1972 (Clean Water Act, CWA) established regulations for water pollution in the United States. Further, the CWA gave the EPA the ability to take legal action against firms or individuals who emitted pollution from point sources into navigable waters without first obtaining a permit. The Clean Water Act of 1977 enhanced the EPA's control over regulations established in the CWA. (LawBrain, 2012) Additionally, the Clean Water Act of 1977 established and enforced a system of best practices for water pollution control.

The Energy Policy and Conservation Act of 1975 is the only energy-focused sustainability policy promulgated in the 1970s in Table 2. Among other things, this act is notable for the creation of the strategic petroleum reserve and the establishment of corporate average fuel economy (CAFE) standards. CAFE standards established vehicle fuel-efficiency requirements for automobile manufacturers. (National Highway Transportation Safety Administration, 2002) CAFE standards required manufacturers to meet standards based on the average fuel-efficiency of all vehicles they sold, broken down by category. This requirement of fuel-efficiency increases in vehicles reduces consumption of non-renewable resources, while at the same time incentivizes firms to innovate and develop more energy-efficient engines and vehicles.

With a foundation set from legislation passed in the 1970s, legislators were able to expand and fine tune sustainability policy in the following decades. In the 1980s and early 1990s U.S. sustainability policy expanded and began to include provisions targeting renewable energy and energy efficiency. Examples of the fine-tuning of environmental legislation are evident in both the Comprehensive Environmental Response Compensation Liability Act (Superfund) and the Water Quality Act of 1987 (WQA).

In 1980, Congress established the Superfund, which allowed the EPA to require that parties responsible for toxic waste pollution to participate in or pay for cleanup activities (EPA, 2012d). The WQA enhanced the CWA by increasing water-quality standards and requiring that states adopt a set of numeric criteria for certain water pollutants, some of which were previously unregulated. (EPA, 2012g) This inclusion of previously unregulated materials and adjustment of standards illustrates Congress' effort to fine-tuning sustainability policy. In relation to economic theory, toxic and hazardous waste legislation allowed the EPA to force firms to internalize the cost of externalities they created. This results in an alignment of the PMC and SMC curves of Figure 3.

The Energy Security Act and the Alternative Motor Fuels Act are the energy-focused sustainability policies that were enacted in the 1980s. In 1980, Congress passed the Energy Security Act, which included six component acts. Each component act targeted a specific area of renewable energy or energy-efficiency. The goal of this act, like many subsequent energy policies, was to reduce the United States' dependence on foreign oil supplies. The Energy Security Act attempted to achieve this goal through incentives to increase alternative energy production. In 1988, the Alternative Motor Fuels Act added provisions to the CAFE standards to promote alternative fuels. (National Highway Transportation Safety Administration, 2002) The Department of Transportation (2002), along with the DOE and EPA, found that changes to CAFE standards by AMFA incentivized an increase in alternative fuel vehicles but infrastructure deficiencies mitigated the effect. The report also noted that alternative fuels were used to offset increases in gasoline consumption for other vehicles and resulted in an average increase of gasoline consumption and greenhouse gas emissions by less than about one percent.

Three initiatives expanded sustainability policy in the 1990s through three initiatives: the Oil Pollution Act of 1990, the Clean Air Act Amendments (CAAA) of 1990, and the Energy Policy Act of 1992.

The Oil Pollution Act of 1990 was a direct response to the Exxon-Valdez oil spill in Alaska and established the Oil Spill Trust Fund to help fund the cleanup of future spills. In addition to provisions regarding the cleanup and payment of damages caused by oil spills, the Oil Pollution Act enhanced regulation for offshore oil drilling and the transportation of oil.

The CAAA expanded the Clean Air Act by increasing the standards for a broader range of pollutants. The CAAA also notably included Title IV, the SO_2 cap and trade system (EPA, 2007). This system capped the amount of SO_2 that could be emitted in the United States for a given year. The EPA allotted permits to emitting entities that allowed them to emit SO_2. These entities were then able to trade or sell permits freely amongst one another. The EPA fined firms who emitted SO_2 in excess of the limit for which they had permits. This act demonstrates the overlap between environmental and energy policy as burning coal for electricity is the primary source of SO_2. In addition to Title IV, the Clean Air Act Amendments allowed Native American tribal regions to establish their own regulations regarding air pollution in their territory, and expanded the National Emissions Standards for Hazardous Air Pollutants to include 189 new pollutants.

One can examine the SO_2 cap and trade program through the framework of Figure 3. The goal of the program was to regulate the level of SO_2 emissions in the United States in a more efficient way. The base for comparison is a case in which each firm is obligated to produce only the Q_opt level of pollution. Suppose that individual producers of SO_2 have PMC curves that differ based on their ability to institute pollution reduction measures. Society may achieve efficiency gains may by allowing firms who can more cheaply reduce emissions to sell permits with other firms. Thus, the same level of pollution reduction is achieved in a less costly manner.

The Energy Policy Act of 1992 covered a range of topics regarding energy usage including: federal energy-efficiency standards, renewable energy sources, water conservation, new technologies for energy-efficiency, energy audits, and efficiency standards for the fleet of vehicles maintained by federal agencies. These efforts reduced the energy usage and pollution production of federal agencies.

Sustainability policy enacted after 2000 focused significantly on energy—promoting both energy efficiency and alternative energy—as evidenced by four laws: the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007 (EISA), the Energy Improvement and Extension Act of 2008 (EIEA), and the American Recovery and Reinvestment Act of 2009 (ARRA). In addition, the government enacted three executive orders pertaining to the energy efficiency of federal agencies: Executive Order 13221, Executive Order 13423, and Executive Order 13514.

The Energy Policy Act of 2005 extended and enhanced many of the provisions in the Energy Policy Act of 1992, targeted energy efficiency and renewable energy production, and included a change to daylight savings time.

EISA took action to reduce energy consumption and increase domestic energy production. EISA promoted increased vehicle fuel economy by increasing CAFE standards and promoting electrified transportation systems (i.e., electric cars). The purpose of EISA is:

> To move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes.

To accomplish these stated goals, EISA included a variety of initiatives to reduce fuel consumption and increase domestic energy production. Increasing CAFE standards and promoting electrified transportation systems (i.e., electric cars) improved vehicle fuel economy. EISA established R&D programs to incentivize biofuel, solar, geothermal and hydrokinetic production. In addition, Congress included energy-efficiency measures and support for the development of green jobs in the act. EISA contained provisions related to the energy distribution and management systems; these provisions focused on the development of an improved electrical distribution network (i.e., a smart grid) and promoted R&D on technology designed to increase the efficiency of energy distribution.

EISA also addressed the energy efficiency of buildings and industry. Several initiatives promoted the reduction of energy consumption of public and private buildings. Provisions in EISA required newly constructed or renovated federal buildings to meet new standards for fossil fuel use and carbon reduction. Other provisions established grant programs to help public entities implement energy-efficiency and sustainability projects.

EIEA continued and enhanced support for sustainable energy initiatives and contained four titles: Energy Production Incentives, Transportation and Domestic Fuel Security, Energy Conservation and Efficiency Provisions, and Revenue Provisions. Energy Production Incentives covered a range of renewable and alternative energy areas. This title extended the Renewable Energy Tax Credit through 2016 and expanded the program to cover wind, hydrokinetic, and geothermal sources. Transportation and Domestic Fuel Security provisions focused heavily on biomass, biofuels, and biodiesel, but also included provisions concerning electric vehicles and other non-biofuel areas. Among these provisions were tax credits supporting innovation and production in the area of renewable-energy and energy-efficient transportation. Energy Conservation and

Efficiency focused on incentives to reduce energy consumption. The Revenue Provisions in the EIEA centered on oil revenues, closing foreign tax loopholes, and increasing the per-barrel tax that provides revenue for the Oil Spill Liability Trust Fund.

ARRA, intended to provide stimulus to many areas of the lagging economy, provided funds for energy-efficiency and renewable-energy projects. (DOE, 2012a) Renewable-energy projects funded by the ARRA included construction of new renewable energy sources such as geothermal, solar, wind, hydroelectric, and biomass refineries and feed stocks. The government implemented grants, tax credits, and Treasury grants to help fund the development of new renewable energy sources. Further, ARRA provided funds for energy-efficiency projects related to green building construction and industry energy-efficiency. Funding for the adoption of energy-efficiency technologies in residential, commercial, and industrial buildings supported green-building projects. In addition, the ARRA increased the levels of funding for the Superfund. (EPA, 2012a)

Executive orders 13221, 13423, and 13514 all related to the energy efficiency of federal agencies. Executive Order 13221 set the requirement that agencies use electronics with standby-power features. (DOE, 2009) Executive Order 13423 was broader in scope and set goals for agencies regarding the efficiency of their buildings, toxic chemicals use, greenhouse gas emissions, water consumption, renewable energy consumption, and vehicle fleet's petroleum use (EPA, 2012j), Executive Order 13514 built upon Executive Orders 13221 and 13423 by increasing the stringency of the requirements (DOE, 2012b). Additionally, Executive Order 13514 directed federal agencies to assign a Senior Sustainability Officer, establish a strategic sustainability performance plan, and make efforts to improve the sustainability of their buildings. (EPA, 2012k) These three executive orders reflect a continued focus on energy efficiency and related environmental issues such as greenhouse gasses. They also underscore the continued movement towards a more sustainable government, a trend established by NEPA in 1969.

Overlap of U.S. Innovative Activity and Sustainability Policies

During the last decade, the level of overlap between innovative activity and sustainability policies has increased. Policies addressing sustainability have included provisions that allocate public funds for privately performed research. Meanwhile, innovative activity policies have included provisions that incentivize investments in R&D towards sustainability-related fields such as alternative energy. Table 3 lists the legislation that overlaps both innovative activity and sustainability. The table provides information on each law's primary focus and support for sustainability innovations.

Of the ten policies included in Table 3, seven were enacted after 2000. The impetus for these polices included: increasing energy prices due to rapid development in high-population markets, advances in the science and understanding of climate change, and an increased awareness of the impact human activity has on the environment.

The legislation that provided direct funding for R&D related to sustainability are: the Energy Security Act of 1980, the Energy Policy Act of 1992, the Biomass R&D Act, the Energy Policy Act of 2005, the EIEA, the EISA, the ARRA, the America COMPETES Act, and the America COMPETES Reauthorization Act. Research areas emphasized for investments included alternative and renewable energy technologies such as solar, hydrokinetic, biofuels, clean coal and other low-emission fossil fuels. Energy-efficiency technologies emphasized included green building technologies, energy-efficient electronics, and fuel-efficient electric vehicles. Additionally, EISA provided funds for research and development of carbon capture and sequestration technologies. In relation to the economic theory of Chapter 2, these funding programs focused on the innovative activity side of the dual market. They reduced innovative activity costs and thereby increase the private rates of return to the innovative activity they funded.

Table 3. Overlapping Policies

Policy	Year	Primary Focus	Sustainability R&D Support
Energy Policy and Conservation Act (PL 94-163)	1975	Reduce dependence of foreign oil production, increase vehicle fuel efficiency	Established CAFE standards. Leading to R&D targeting energy-efficiency of motor vehicles.
Energy Security Act (PL 96-294)	1980	The ESA's primary focus was clean alternatives to the use of foreign oil as a fuel.	Provided funds for R&D towards environmentally friendly power sources.
Energy Policy Act of 1992 (PL 102-486)	1992	The Energy Policy Act of 1992 covered a broad range of energy topics including: federal vehicle fleet standards, federal building energy efficiency, renewable energy programs, toxic waste disposal and many other topics.	Provided funds for: electric and hybrid vehicle demonstration program, clean coal R&D, and for renewable energy R&D.

Policy	Year	Primary Focus	Sustainability R&D Support
Biomass R&D Act (PL 106-224)	2000	Provided support for R&D targeting the production of Biofuels including the production of biomass, the development of products derived from biomass and the increasing the efficiency of biofuel creation.	Established grant programs to fund R&D on biofuels and related industries
Energy Policy Act of 2005 (PL 109-58)	2005	The Energy Policy Act of 2005 covered a broad range of energy topics. Provisions covered oil and gas production, energy efficiency, renewable energy, and many other energy-related topics.	R&D support for many energy-efficient and renewable energy technologies such as hydrogen power, high performance buildings, and more.
Energy Independence and Security Act of 2007 (PL 110-140)	2007	Overarching goal of EISA was to transition the United States to greater energy independence and security through reduced dependence on foreign oil via energy efficiency and renewable energy.	Established R&D programs to incentivize biofuel, solar, geothermal and hydrokinetic production. Additionally EISA provided funds for R&D on carbon capture and sequestration.
Energy Improvement and Extension Act of 2008 (PL 110-343)	2008	The EIEA's primary focus was to continue and enhance support for sustainable energy initiatives.	Support for innovation in the field biofuels was provided via tax credits.
American Recovery and Reinvestment Act of 2009 (PL 111-5)	2009	Large piece of legislation introduced to counteract the effect of the Great Recession.	Funding for R&D and adoption of alternative energy and energy-efficiency technologies.

Policy	Year	Primary Focus	Sustainability R&D Support
America COMPETES Act (PL 110-69)	2007	The America COMPETES Act's focus was STEM education, increasing scientific research at the National Science Foundation, and other support for American research investment.	Established the Office of Innovation and Entrepreneurship in the Department of Commerce.
America COMPETES Reauthorization Act (PL 111-358)	2010	The America COMPETES Reauthorization Act expanded upon the America COMPETES Act. It provided higher levels of funding support over an expanded range of areas.	The 2010 reauthorization of the bill includes funding for many agencies conducting science and engineering research, including ARPA-E.

In addition to direct funding, the government implemented tax credits and public procurement to support renewable energy and energy-efficient technologies. These credits initially took the form of renewable energy tax credits, which EIEA further extended. The Energy Policy Act of 1992 and Energy Policy Act of 2005 as well as Executive Orders 13221, 13423, and 13514 require government procurement of energy-efficiency products and renewable energy technologies. These procurement programs and requirements address the inefficiencies of dual-market failure of green technologies by creating demand for sustainability enhancing products. This increase in demand raises the private marginal benefit to firms in the innovation half of the dual market by providing innovators greater ability to capitalize on their efforts.

Summary

This chapter overviewed government action addressing both sides of the dual-market described in Chapter 2. Sections 3.1 and 3.2 examined policies addressing one-half of the market; Section 3.3 overviewed the policies that overlapped both halves of the dual market.

This overview of innovative activity and sustainability polices provides context to the creation of the NC Green Business Fund. The NC Green Business Fund was created in 2007, the same year that Congress enacted EISA. Closely related policies enacted before 2007 include the Biomass R&D Act, the Energy Policy Act of 2005, and multiple Executive Orders. Similar to the NC Green Business Fund, these predecessor policies provided support for biofuels, green buildings, and other environmentally friendly technologies. This suggests that the North Carolina State Legislature operated in line with policy of the federal government when it acted to create the Fund.

CHAPTER IV

GOVERNMENT ACCOUNTABILITY

Government accountability has been a long-standing tradition in the United States. In the Declaration of Independence, President Thomas Jefferson (2012, originally 1776) stated that government's authority is derived from "the consent of the governed." This statement would set the foundation of government accountability as an important tenant for the United States. In the Gettysburg Address, President Abraham Lincoln (as cited in White House, 2012) stated that the U.S. government is "of the people, by the people, for the people." Together, these statements reflect the idea that the government is to be accountable to U.S. citizens.

The purpose of this chapter is to articulate the importance of government accountability by discussing the theory of government inefficiencies and providing a historical perspective of accountability in the U.S. government. The theory presented will frame the discussion of policies, although it was not necessarily used to guide the crafting of policies. This discussion of government accountability motivates efforts to analyze government activities and initiatives discussed elsewhere in this dissertation.

Economic Theory of Government Inefficiencies

The economic theory of government inefficiencies centers on the possibility for government to institute policies that create new inefficiencies. That is to say, government intervention is not without its potential drawbacks. Intervention may lead to inefficiencies not experienced by markets acting on their own. Examination of these drawbacks, their causes, and ways to address them can lead to more efficient public policy.

Researchers have proposed several theories of government failure (Wallis and Dollery, 1999). The central theme to these theories is the potential for government intervention to create inefficiencies. These inefficiencies can come about in a variety of ways. First, a government agent acting, as a rational individual, can make choices that maximize their own utility and not the welfare of society. This is a direct analogy to the typical principle-agent problem, with society playing the role of the principle and the government employee playing the agent. Second, government can over subsidize products or services. Over subsidization can lead to deadweight loss due to higher than optimal production. Third, government can impose inefficient regulation into markets (Grand, 1991).[11]

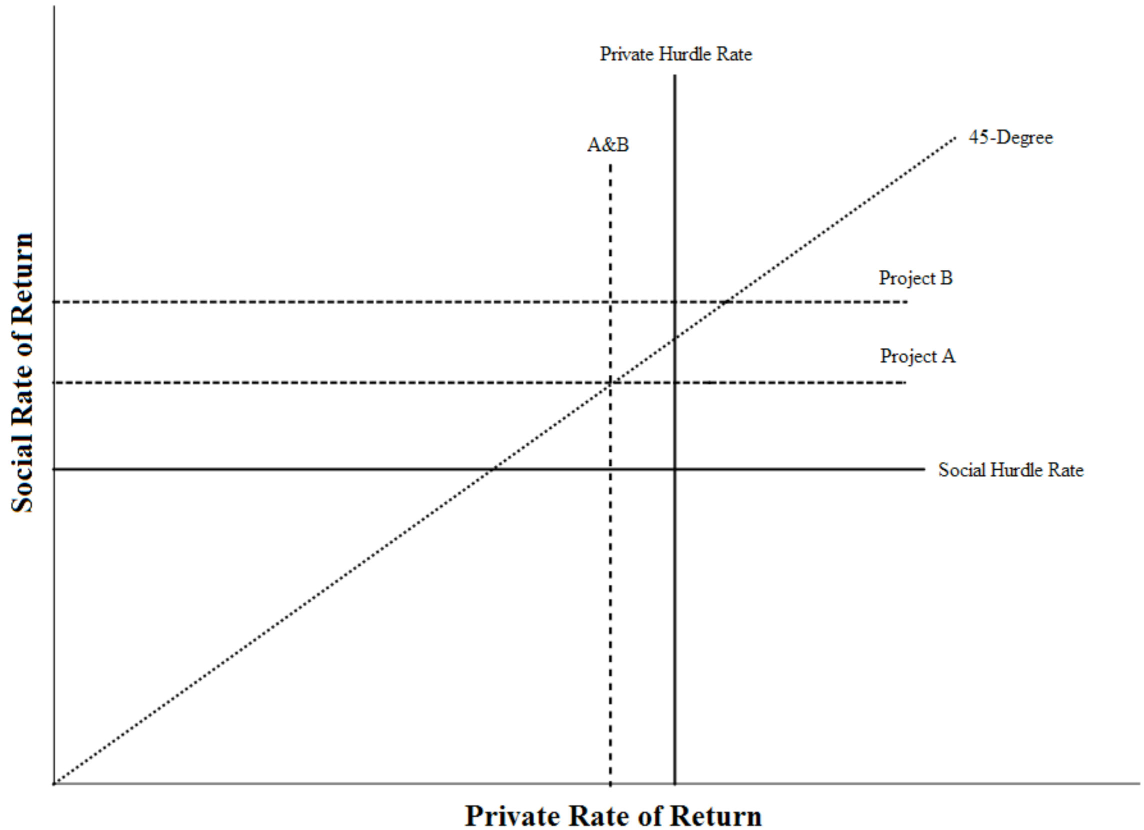
The Principal-Agent Problem

A principal-agent problem exists when the choices or actions of the agent (e.g., the government employee) do not align with the optimal choice for the principal (e.g., society). The principal agent problem could arise in many aspects of government. Elected officials may choose to support interests of lobbying groups over those of their constituents in order to ease reelection. Federal regulators may be lax in enforcement of regulations to secure future employment at regulated firms. Procurement officers may

[11] Government investment crowding-out is an additional possibility. Although research does not reach a definitive consensus on the matter, many studies suggest public funds increase private R&D expenditure or have no effect. (Zuñiga-Vicente et al., 2012)

make contracts with firms that they have some personal interest in. That said, these are examples of the most egregious cases.

Figure 4. Inefficient Project Support



One may consider an example of the principal-agent problem within the context government support of innovative activity using Figure 4, which is a modified version of Figure 2. Suppose the government could fund one of two projects, A and B. In this example project B has a higher social rate of return than project A. Both projects have the same private rate of return, which is indicated by the vertical lined labeled A&B. Note that the private rate of return is below the private hurdle rate, and thus both projects are suitable candidates for support. Suppose the government agent responsible for choosing the project to fund has a personal interest in a project A. If the agent, operating on their personal incentives, choses to fund project A over project B then the allocation of resources is less than socially optimal due to forgone benefits to society in the form of higher social returns.

Government may pursue several solutions to the principal agent problem, two of which will be discussed. The first solution to this problem is to assign decision-making responsibilities to carefully chosen, non-biased individuals or committees. Committees offer the added benefit of potentially varied viewpoints and knowledge bases. Diversity in views and knowledge allows for deeper understanding of the choices to be made. A benefit of committees is that they do not require choices to be made before this solution is implemented. A second possible solution to the principal-agent problem is to review the decisions of agents and determine if the allocation of resources is socially optimal given the choice set. Review processes range in complexity from simple supervisor reviews of employee choices to detailed analyses of project performance. A drawback of review as a solution to the principal agent problem is that it is an *ex post* solution, requiring decisions to have been made which can be reviewed. Government is able to employ both of these solutions to address the principal-agent problem.

Over Subsidization

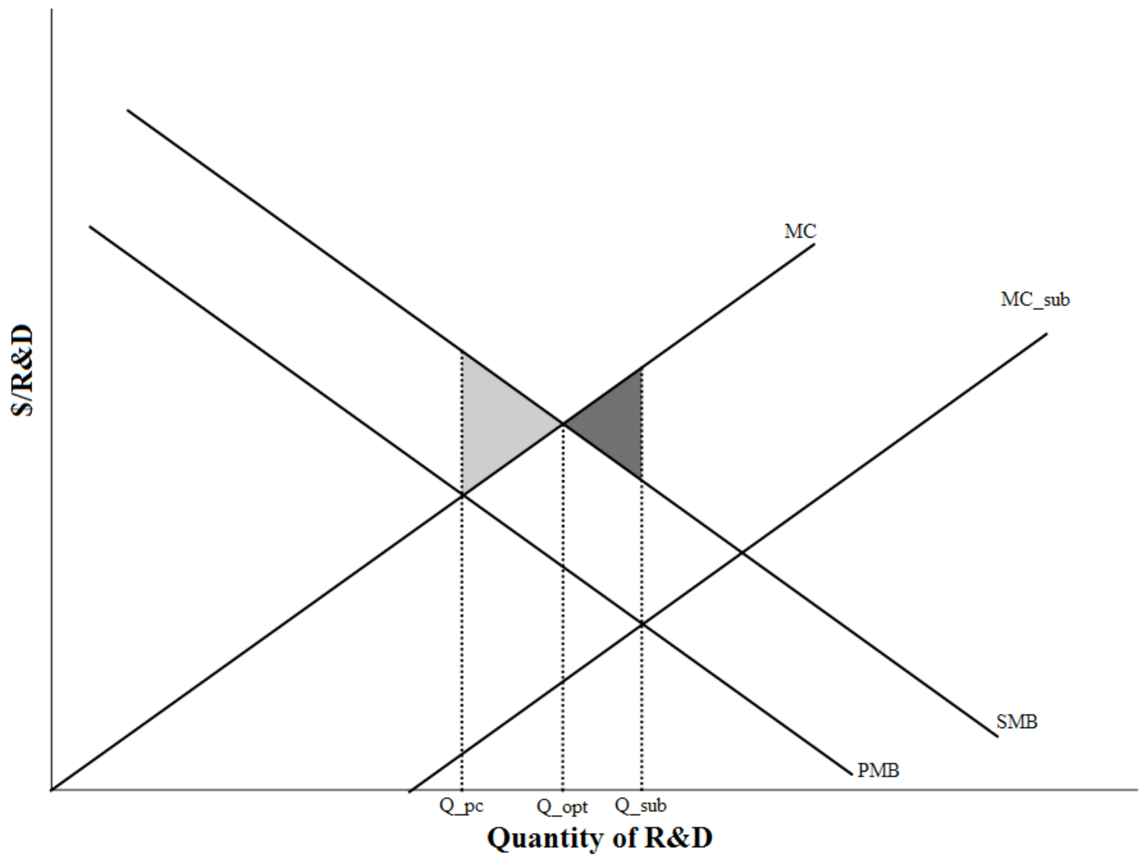
Over subsidization is the second way in which government inefficiency can arise. Over subsidization is defined here to be the result of government intervention in a market that leads to an inefficient quantity of production, either over production of a good or under production of a bad (e.g., too much pollution abatement). This overproduction can arise from a range of policies including direct subsidies, quantity or price controls, and tax credits. The common thread of these policy tools is that they influence the chosen level of output in a market. To examine over subsidization, this subsection will focus on direct subsidies.

One can consider over subsidization arising from direct subsidies using the framework of Figure 1. Below, Figure 5 expands on Figure 1 to illustrate the inefficiency created by over subsidization. In Figure 5, the horizontal axis represents the quantity of R&D produced, while the vertical axis represents the price or value per unit of R&D. The lines labeled PMB and SMB represent the social marginal benefit and private marginal benefit, respectively. The line labeled MC represents the marginal cost of R&D to both society and the private agent. The socially optimal level of R&D is given by Q_opt and is the level at which the marginal cost of R&D is equal to the social marginal benefit.

Without government intervention, the private agent will choose to produce the quantity of R&D given by Q_pc. At the level of R&D represented by Q_pc, the social marginal benefit to R&D is greater than the social marginal cost. As described in Chapter 2, the lightly shaded region of the figure is the deadweight loss. This deadweight loss occurs due to under provision of R&D and represents forgone benefits.

The government can intervene in this market by providing a direct per-unit subsidy (sub) to the private agent, reducing their marginal cost of R&D at all quantities. The line labeled MC_sub represents the marginal cost to the private agent when the government provides the subsidy. Given this new marginal cost curve, the agent will choose to conduct the quantity of R&D given by Q_sub. This quantity is the output level at which the agent's private marginal benefit is equal to the subsidized marginal cost.

Figure 5. Over Subsidization



The quantity given by Q_sub is greater than the quantity given by Q_opt, the optimal quantity of R&D. Although the firm faces a reduced marginal cost, society's marginal cost is unchanged, as they must pay for the subsidy itself. At Q_sub the social marginal benefit is lower than the unsubsidized marginal cost. That is to say, the benefit to society per-unit of additional R&D is less than the per-unit cost. This is the case for all quantities of R&D greater than Q_opt (e.g., Q_sub). The darker shaded region depicts the deadweight loss that occurs due to overproduction of R&D.

Potential solutions to the over subsidization problem aim to ensure the efficiency of markets in which the government has intervened. Before an intervention is enacted the agency responsible can conduct prospective analyses to estimate impacts and determine optimal policy parameters. By doing so, they are able to make informed choices and potentially more able to achieve efficient market outcomes. Following the implementation of a market intervention, the government can conduct retrospective analyses and reviews. By conducting reviews, government is able to fine-tune policy and move the market toward an efficient outcome.

Inefficient Regulation

The third method through which government can create inefficiency is regulation. Regulation here refers to restrictions or barriers imposed by the government to address some existing market inefficiency. Often these regulations are not pecuniary in nature but govern some interaction. Examples of regulations include: safety rules for job sites, drug approval processes, intellectual property right laws, and motor vehicle fuel-efficiency requirements. The government inefficiency need not be that the regulation is imposed, but that it is imperfect in its implementation.

One example of potentially inefficient regulation affecting innovation is the Food and Drug Administration's (FDA) approval process of new drugs. Winston (2006) suggests that the FDA is too stringent in its approval process of new drugs and that similar entities in other countries are much quicker to approve new drugs. The delays in the approval process that could lead to lost lives and high costs are the centerpiece of his argument.

Another example of potentially inefficient regulation is the collection of laws regulating intellectual property (IP) rights. Researchers have disagreed over the appropriate strength of IP laws. Intellectual property right laws that are too stringent or too vague could lead to the stifling of innovative activity due to the potential cost of litigation. On the one hand, Winston (2006) is critical of the ease at which patents can be applied for and received since the passage of the Federal Court Improvements Act of 1982 and argues that the ease of litigation restricts innovation. On the other hand, Bernanke (2011) suggested that stronger intellectual property rights would reduce the underinvestment caused by spillovers. That said, Winston provides positive comments for the changes made to the patent laws covering brand name and generic drugs, which he builds upon to suggest that market specific laws could be enacted to increase social welfare.

Similarly to the previously discussed government inefficiencies, the solutions to inefficient regulation are analyses of proposed regulation prior to implementation and review of the regulations after they are implemented. Although in practice neither of these solutions is likely to be perfect, a process of continual fine-tuning can move policy towards efficient regulation.

Capture Theory

To this point, discussion of the role of government and inefficiency stemming from government intervention has focused on what Laffont and Tirole (1993) describe as “public interest” theory. They note that public interest theory “emphasizes the government’s role in correcting market imperfections such as pricing and environmental externalities” (p. 475). Alternatively, one can model the actions of government using “capture” theory that focuses on the power of non-government agents to influence the actions of government agents. The effect of this influence is analogous to the principal-agent problem presented above.

Laffont and Tirole outline a basic model of capture theory. In their model, the firm acts as the agent, the regulatory agency is a supervisor, and the legislative body is the principal. The legislative body parallels the role of government in public interest theory and attempts to maximize social welfare. In the basic model, the legislative body establishes laws that will maximize social welfare. Transactions between the firm and the regulatory agency can impede welfare maximization when the firm provides compensation to the regulatory agency or individual agents in return for favorable regulation and lax enforcement. Regulatory agencies are then able to limit the information they provide to the legislature to hide any collusion.

An alternate to exerting influence over the regulatory agency, the firm could attempt to influence members of the legislative body. The firm could exercise this influence through means such as political campaign donations, grass-roots efforts, and statements of support from industry lobbies. The influenced members of the legislative body play the role of the supervisor while the rest of the legislature is the principal. In this scenario, sub-optimal legislation and a restricted ability of the regulatory agency are additional mechanisms impeding welfare maximization.

The legislative body can implement policies to mitigate the effects of regulatory capture. One policy option is to establish strict reporting requirements for agencies that are enforced by independent oversight agencies. These requirements mitigate the ability of regulatory agencies to withhold information from the legislative body. Another policy option is to limit the ability for regulators and firms to conduct transactions. Particular examples of this option include outlawing bribes and preventing agents from working in the regulated industry after retirement.

Historical Perspective of Government Accountability

The prior discussion of theory of government inefficiency provides a framework to discuss government accountability policies. Link and Scott (2011a, p.20) wrote: “Fundamental to public support of economic activity is the public sector’s awareness of its accountability for its use of public resources.” This section follows the discussion they outlined, and frames the legislation using the theory presented in section 4.1.

The laws presented below focus on review of decisions, performance, and resource usage. Oversight is intended to create efficiency increases through the reduction of waste and mismanagement. This focus on review by the legislation displays the importance of *ex post* evaluation as a solution to the government inefficiencies presented above. The lack of legislation regarding pre-action screening and decision-making does not reflect ignorance. Instead, it reflects the fact that the particulars of efficient and effective decision making vary to such a degree that sweeping legislation would impose unreasonable barriers to potentially beneficial action. Indeed, ex-ante solutions are present in many policy pieces in the form of advisory committees and prospective reporting requirements.[12]

Table 4 provides information on U.S. government accountability legislation.

Table 4. U.S. Government Accountability Legislation

Policy Name	Year	Purpose and Effects
Budget and Accounting Act of 1921 (PL 67-13)	1921	Created the Government Accounting Office and established the position of Comptroller General. Intended to increase the efficiency of government expenditures.
Chief Financial Officer Act of 1990 (PL 101-576)	1990	Enacted with the purpose of increasing fiscal accountability of the departments of the federal government. Created the Office of Federal Financial Management and the position of Chief Financial Officer at federal agencies.
Government Performance and Results Act of 1993 (PL 103-62)	1993	Continued efforts to increase fiscal responsibility and accountability in the U.S. government. Established reporting requirements for federal agencies.
Government Management and Reform Act of 1994 (PL 103-356)	1994	Requires federal agencies to submit audited financial reports to the director of the OMB.

[12] The NC Green Business Fund's enabling legislation requires both a committee to overview applications and extensive prospective analysis on proposed projects.

Policy Name	Year	Purpose and Effect
Federal Financial Management Improvement Act of 1996 (PL 104-208)	1996	Established a uniform financial accounting system for federal agencies.
Government Accounting Office Human Capital Reform Act of 2004 (PL 108-271)	2004	Changed the name of the Government Accounting Office to the Government Accountability Office. Altered the compensation scheme for GAO employees.

Link and Scott begin their discussion of the legislative history of government accountability with the creation of the General Accounting Office (GAO). The Budget and Accounting Act of 1921 established both the GAO and the Bureau of the Budget in the Treasury Department. The Bureau of the Budget would later be transferred to the Office of the President and become the Office of Management and Budget (OMB). The head of the GAO is the Comptroller General. In addition to the bookkeeping and accounting duties of the United States the Budget and Accounting Act of 1921 assigned the Comptroller General the following duty (PL 67-13):

> investigate, at the seat of government or elsewhere, all matters relating to the receipt, disbursement, and application of public funds, and shall make to the President when requested by him, and to Congress at the beginning of each regular session, a report in writing of the work of the General Accounting Office, containing recommendations concerning the legislation he may deem necessary to facilitate the prompt and accurate rendition and settlement of accounts and concerning such other matters relating to the receipt, disbursement and application of public funds as he may think advisable. In such regular report, or in special reports at any

> time when Congress is in session, he shall *make recommendations looking to greater economy or efficiency in public expenditures* [emphasis added].

The emphasized fragment in the passage highlights the role the GAO plays in government accountability. Congress, by assigning duties to look for greater efficiency in public expenditures, took the first legislative step towards creating a more accountable federal government. Over 80 years later, Congress passed the Government Accounting Office Human Capital Reform Act of 2004. It was a minor piece of legislation that changed the compensation scheme for the employees of the GAO but also changed the name of the Government Accounting Office to the Government Accountability Office to reflect better the role it plays inside the federal government. Given the responsibility to review the use of government funds, the GAO provides a potential solution to government inefficiencies presented in section 4.1.

Aimed at the principal-agent problem presented in the previous section, the Chief Financial Officers Act of 1990 was legislation designed to increase the fiscal accountability of the departments of the federal government. Congress found that billions of dollars were "lost each year through fraud, waste, abuse and mismanagement" (PL101-576) and that these losses could be reduced through improved management. The act created the Office of Federal Financial Management in the OMB. It also created the position of Chief Financial Officer (CFO) at federal agencies. These CFOs were appointed by the president and reported to the director of agency. They were given responsibility for the financial management and accounting systems of the agency and oversight of the financial execution of the agency's budget. The act required the CFOs of each agency prepare annual revisions of the five-year financial plan of the agency for congress. One can observe that the Chief Financial Officers Act continues the trend of review started by the creation of the GAO.

In continued efforts to increase fiscal responsibility and accountability, the Government Performance and Results Act (GPRA) of 1993 established requirements for federal agencies to report on the progress and results of their programs. Congress found that waste and inefficiency were present in the federal government and this waste led to an undermining of public confidence. The GPRA required that government agencies make strategic plans that include the mission of the agency, goals and objectives, plans to achieve those goals and objectives, how those goals and objectives related to the mission, potential external obstacles to the mission, and a description of program evaluations used to create and revise the mission. The GPRA also required that agencies submit annual performance plans and reports to the OMB. The annual performance plans had many similar requirements to the strategic plan, but they called for establishing objective and quantifiable measures of results unless authorized to do otherwise. If quantifiable measures were unfeasible the agency and the OMB could agree to use some qualitative measures. The GPRA follows in the same trend of the Chief Financial Officers Act, but it does so from a different perspective. While the Chief Financial Officers Act requires agency CFOs to present fiscal plans to Congress, GPRA requires that agencies present progress and results reports for each program. By investigating agency actions, a greater level of oversight is provided.

Two remaining acts complete the overview of accountability legislation: The Government Management and Reform Act of 1994 and the Federal Financial Management Improvement Act of 1996. The Government Management Reform Act requires that each agency provide an audited financial report to the director of the OMB. Each financial statement must reflect the overall financial position of the agency's offices and the results of operations. In addition to this, the Secretary of Treasury and the director of the OMB must prepare a government-wide financial statement. The Federal Financial Management Improvement Act is the last policy covered in this section. Congress found that federal accounting practices did not accurately report the costs of programs and activities. It also found that waste and inefficiency undermined the American people's confidence in the federal government. To address this issue, this act established a uniform financial accounting system for federal agencies.

The legislation discussed above covers the history of legal requirements established to increase accountability in the federal government. Increasing reporting requirements and strengthening accounting standards have continually pushed agencies and departments towards higher levels of accountability. This trend of more stringent requirements and standards reflects one of the solutions to government inefficiency, post-performance evaluation and review.

Summary

Since before the founding of the United States, and throughout its history, the idea that the government is accountable to its citizens for the use of public resources has been a central concept. This chapter overviewed the history of government accountability in the United States. Section 4.1 presented the potential for government inefficiency, the methods by which it can occur, and provided discussion of potential solutions. Section 4.2 reviewed federal legislation whose purpose is to increase the accountability of federal agencies and reduce government inefficiency.

Although it is important to understand the possibility that government intervention can lead to undesirable outcomes, it is not always, and, with well-designed policy, likely not often the case. Grand (1991, p. 442) summarized this point in the following statement:

> Finally, it is important to re-emphasize that a study of government failure does not imply that governments always fail, still less that markets always succeed. Whether a particular form of government intervention creates more inefficiency or more inequity than if that intervention had not taken place is ultimately an empirical question and one that is by no means always supported by the evidence. Governments sometimes succeed, a fact that should not be lost to view in the current glare of the market's bright lights.

CHAPTER V

NORTH CAROLINA'S GREEN BUSINESS FUND

North Carolina's Green Business Fund (hereafter, the Fund) was a grants program established by North Carolina General Statute §143B-437.4(a). The Board of Science and Technology (hereafter, the Board), within the North Carolina Department of Commerce, operated the Fund from fiscal years 2008 through 2011. The purpose for the Fund was to provide (http://www.ncscitech.com/grant-programs/green-business-fund):

> competitive grants to help NC small businesses develop commercial innovations and applications in the biofuels industry and the green building industry, as well as attract and leverage private sector investments and entrepreneurial growth in environmentally conscious technologies and renewable energy products and businesses.

Programs targeted by the Fund fall into one of three categories: projects that focus on biofuel development and production, projects that focus on green building technologies, and projects that promote private investment in green industry in North Carolina.

North Carolina provided grant funding for the program for fiscal years FY2008 and FY2009, while the American Recovery and Reinvestment Act (ARRA) provided funding for FY2010 and FY2011. This dissertation considers only state investments in FY2008 and FY2009. Pragmatic considerations, predominantly the availability of survey data from participants in the program, drive the focus on FYs 2008 and 2009. The Board conducted a detailed survey in 2012 of firms receiving grants from which information is available, for among other things, an economic evaluation of the program. This limitation should not be interpreted to mean that ARRA funding of green businesses in North Carolina or elsewhere is of lesser importance. On the contrary, efforts toward government accountability at all levels are important and such an effort should be undertaken in the future.

Of the legislation presented in Chapter 3, the Energy Independence and Security Act (EISA) of 2007 is the act that is most similar to the Fund. In addition to being passed in a similar time frame, the Fund and EISA promote sustainability innovations and, indirectly, the creation of green jobs. The particulars of support in each area vary: the Fund focuses on biofuels while EISA supported a broader range of alternative energy technologies, the Fund supported the development of green building technology whereas EISA promoted adoption, both policies provided indirect support of green jobs through the expansion of the green industry.

The remainder of this chapter provides background on the Fund's operation, discusses similar programs in other states, and examines the proliferation of similar programs.

Operation of the Fund

This section details the operation of the Fund by providing an overview of the application, selection, and disbursement processes. Changes to the rules governing the Fund's operation from FY2008 to FY2009 necessitate detailing each year independently.

The North Carolina State Legislature allotted $1,000,000 to the Fund for each fiscal year under consideration. Of the allotted $1,000,000, the Legislature allocated $50,000 to the Board for the cost of administering the program. The Board disbursed the remaining $950,000 as grants with a maximum grant size of $100,000.

The Board established an advisory committee to review all applications that met the requirements put forth. The advisory committee consisted of scientists, engineers, and qualified experts, some of whom were members of the Board. The Board took care to avoid conflicts of interest in the selection of committee members.

Applications in FY2008

The Board required eligible entities to submit project proposals to be considered for funding.[13] The FY2008 proposals consisted of four elements: a proposal cover, a project summary, a technical proposal, and a proposed budget. To receive a grant in FY2008, applications were due by the close of business on April 30, 2008.

Applications in FY2009

The application process and the required materials changed significantly from FY2008 to FY2009. The Board implemented an additional phase, the Pre-Proposal phase, to eliminate unrealistic and inappropriate applicants early in the process. In the Pre-Proposal phase applicants submitted a series of short—250 or fewer words—descriptions of their proposed projects, the impact their project would have, and details on the entity applying.

[13] Eligible entities included businesses with fewer than 100 employees, local governments, and other public entities (e.g., colleges and universities). Eligibility also required applicants to be located in North Carolina.

The Board screened Pre-Proposals and selected those that met the criteria regarding the scope of the project and eligibility requirements to continue with the application process. The Board notified selected applicants and advised them to submit a complete project proposal. Upon receiving notification that their project cleared the pre-proposal phase, the candidate could then submit an application online through the Board's sciGrant system.[14]

Due to utilization of the sciGrant system, the required materials for application changed significantly from FY2008 to FY2009. FY2009 applications consisted of six parts: contact information, organization information, project information, commercial potential, effect on employment, and a proposal upload.[15] This proposal consisted of the following sections: Project Overview, Project Description, Growing North Carolina's Green Economy, Project Team, Budget, and Supporting Materials. The requirements for each section provided information directly tied to the selection criteria. The application deadline for the FY2009 solicitation was March 20, 2009.

Selection Criteria and Process in FY2008

For the FY2008, the criteria on which the board judged applications were divided into three categories: technical merit, commercial merit, and economic development merit. Technical merit was based on measures of technological merit and feasibility, experience qualifications and facilities, effectiveness of proposed work plan, and budget

[14] sciGrant is an online system used "to apply for and manage grants administered by the Office of Science & Technology." (http://www.ncscitech.com/grant-programs/scigrants-grants-management)
[15] To further ensure eligibility, the Board required applicants include additional certification documents their sciGrant submission. Certification documents include: an Application Certification Document, a Location Certification Document and a Certification of Existence.

realism.[16] The board gave a numeric score to the submitted materials for each of these overall technical merit categories. The scores were summed, with technological merit and feasibility receiving twice the weight of the others, to provide an overall technical merit score. Economic development merit and commercial merit both received qualitative values. The possible qualitative values given were: excellent, very good, average, below average, poor, and insufficient data.

Of the three categories, technical merit received the highest priority. When two (or more) projects received the same technical merit rating the commercial merit rating, economic development merit rating, projected timelines, availability of matching funds, and other factors served as tie breakers. Although both economic development merit and commercial merit were secondary to technological merit, the solicitation materials did not describe a ranking between the two. The Board used these criteria to select the best projects to award funding.

Selection Criteria and Process in FY2009

The selection criteria and process changed from FY2008 to FY2009. The Board established more detailed and specific criteria for FY2009. Additionally, the process for selecting awardees expanded to include multiple phases and input from a broader range of individuals.

[16] Technological merit and feasibility was a subcategory of technical merit.

The FY2009 selection process consisted of three main phases: a review of applications to ensure completeness, a three-stage review of proposals based on the proposed project, and a final selection of projects for funding.

The executive director of the Board and the grant administrator conducted the first phase. In this phase, a review of applications ensured that all the required materials were submitted and complete. Additionally, a review of each application ensured the project's relevance to a priority area.

The advisory committee executed the second phase of selection process. Each application was given three evaluations. These evaluations were: a substantive evaluation focusing on technical feasibility, environmental impact, and value; an industry evaluation focusing on merit of the business plan, market potential, and economic impact; and an inductive evaluation focusing on logic or reasoning of the project.

The executive director conducted the final phase of the selection process. Upon reviewing the suggestions from the Advisory Committee and evaluating commercialization potential for each project, the executive director chose the projects to award funds.

Award Disbursement and Awardees

In both FY2008 and FY2009, the Board disbursed funds to awardees in three phases. One-half of the grant was paid at the time of the award. One-fourth of the grant was paid at the project's halfway point. The remainder of the grant was paid when the final report was submitted.

The Board awarded a total grant value of $950,000 in both FY2008 and FY2009. Of the 85 applications received in response to the FY2008 solicitation, 63 were in compliance with the requirements that were set forth. Of these 63 applications, 13 were selected to receive grants. FY2008 awards ranged from $18,000 to $100,000. For the FY2009 solicitation 14 firms received grants with individual grants ranging from $40,000 to $99,486. Table 5 and 6 list the Board's awardee profiles taken directly from *Green Business Fund 2007-2008 Report* and *Fiscal Year 2009 Report*, respectively.

Table 5. FY2008 Awardees[17]

Program Name	**Funding Amount and Project Description**
Blue Ridge Biofuels of Asheville	$77,737.00 to develop and commercialize the conversion of low quality fatty acids into biofuel through an innovative purification method.
Organofuels of Asheville	$81,944.00 to manufacture algae based fuel for gasoline engines. The project offers the promise of making algae oil products completive with gasoline.
Ecocurrent of Raleigh	$100,000.00 for a novel technological process that will divert hog manure from lagoons and convert it to electric power in an economically viable manner and valuable byproducts such as fertilizer and building materials.
Evans Environmental of Wilson	$75,000.00 to remove residual water in the final stage of biodiesel production. The innovative process will facilitate production of commercial grade biodiesel by 300%.
Alganomics of Southport	$60,000.00 to produce reliable, environmentally responsible, natural and renewable bioproducts from algal sources, and promote the use of renewable energy alternatives. The primary bioproduct is extracted oil/fatty acids for use as a biodiesel fuel feedstock.

[17] Source: North Carolina Board of Science and Technology, 2008b

Program Name	Funding Amount and Project Description
Kyma Technologies of Raleigh	$60,000.00 will work with researchers at North Carolina State University to develop a normallyoff power switch using novel process enabled by high quality substrates developed by Kyma.
3F, LLC of Raleigh	$100,000.00 will develop a new natural fiber reinforced concrete formulation. The resulting lighter weight and yet stronger and tougher concrete will directly enhance the merits of precast concrete. Less weight for the same structural efficiency will reduce material use and dead load, and save transportation cost.
Piedmont Biofuels of Pittsboro	$75,000.00 to implement a cavitational reactor to produce biodiesel fuel. The process uses less energy, has a much smaller physical footprint, and causes a more complete reaction with higher fuel yields.
Nextreme Thermal of Durham	$57,319.00 to manufacture a novel thermoelectric power generator capable of converting waste heat into usable electrical power.
Rain Water Solutions of Raleigh	$18,000.00 to develop the foundation for a new rain barrel manufacturing process that allows mass production capabilities to 1) meet increasing demand in a timely manner and 2) provide an inexpensive, appealing option to consumers desiring to collect rainwater.
Nanotech Labs of Yadkinville	$70,000.00 to develop and commercialize an ultra-capacitor as an energy storage device that has extremely high volumetric capacitance but small overall dimensions.
Phasetek of Greensboro	$75,000.00 to develop a new class of thermal transfer and storage building material for wallboards in order to facilitate thermal efficiency in buildings.
Sencera of Charlotte	$100,000.00 to implement a Photovoltaic Solar Cell production facility in North Carolina based on a new thin-film manufacturing technology.

Table 6. FY2009 Awardees[18]

Program Name	Funding Amount and Project Description
Aerofab Manufacturing Corporation	$45,435.00 to increase the efficiency of mist eliminators in metalworking facilities while decreasing the associated waste stream. Energy and water consumption are decreased.
Caldwell Community College and Technical Institute	$81,000.00 to build a mobile vehicle for green project demonstrations to educate residents and students on the green economy and how it can impact their business.
Centralina Council of Governments	$85,000.00 to integrate existing Charlotte-Mecklenburg Utilities (CMU) facilities and services with new biodiesel and create a market for brown grease (waste oil from food preparation found in the wastewater stream) as an input to biofuel production.
Clean Marine Solutions	$84,602.00 to fund a wastewater treatment system prototype that cleans water used in high-pressure boat cleaning that is currently polluting the water at marinas all over the country.
CPS Biofuels	$50,000.00 to develop a fuel additive made from glycerol (a waste product of biodiesel production). The additive improves fuel economy in gasoline and diesel engines by increasing octane.
EnSolve Biosystems	$50,000.00 to develop an oil water separator technology for small boats that uses bacteria to reduce/remove oil contamination from effluent that flows back into the waterways.

[18] Source: *Fiscal Year 2009 Report (*North Carolina Board of Science and Technology, 2009)

Program Name	Funding Amount and Project Description
Innova Homes	$51,160.00 to develop a hybrid green modular product that merges the energy and material efficiencies of structural polyurethane-insulated floor, wall and roof panels with the factory construction cost and quality efficiencies of modular home construction.
InnovaTech	$53,317.00 to develop a novel method to harvest algae for use in biofuel production. This project will increase the efficiency of algae-to-biofuels conversion.
Microcell Corporation	$80,000.00 to produce environmentally-friendly fuel cells for emergency generator substations as an alternative to existing expensive and hazardous acid cell batteries with a shorter life span.
N.C. State University Solar Center	$95,000.00. Funds will be used towards becoming an accreditation agency for solar thermal manufacturers. Currently Florida is the only U.S. state providing certifications, resulting in a 2-year backlog limiting companies from expanding their business and creating jobs.
PlotWatt (formerly VisibleEnergy)	$40,000.00 to implement a home energy monitoring system that monitors specific appliances and behaviors that directly impact energy consumption. The technology calculates exactly how much energy can be saved.
Semprius	$99,486.00 to develop a Concentrated Photovoltaic system to concentrate solar energy through a lens, reducing the amount of expensive silicone cell needed and improving the overall efficiency of the system while reducing costs.
Vesture Corporation	$75,000.00 to ramp up production of a new home insulation product that uses phase change materials, reducing consumers’ energy costs.

Similar Programs in Other States

Agencies in other states have established sustainability technology (ST) programs. These programs promote the development of sustainability enhancing technology, commercialization of environmentally friendly products and process, and growth of the green industry. The existence of other ST programs suggests the importance of gaining insight from understanding the benefits and impacts of the Fund. One can carry over the insight gained from examining the Fund to better understand other ST programs. This section explores ST programs in other states, their proliferation, and potential determinants of adoption.

Table 7 draws on data from a variety of sources. The databases at DesireUSA.org and the DOE's Advanced Manufacturing Office served key roles in starting the search for programs similar to the Fund. In addition, the author conducted state-by-state Internet searches for solicitations, funding announcements, and program reports. Data collection efforts yielded information on 20 other state-level ST programs in 10 other states.[19] Some ST programs were more directly comparable to the Fund than others.

[19] Including the Fund in NC, there are 21 programs in 11 states.

Table 7. Sustainability Technology Programs[20]

Program Name	State	Years	Purpose
Used Oil Research and Demonstration Program Grants	CA	1994-present	Develop collection technologies and / or uses for recycled or used lubricating oil. "…provides funding for research, testing, or demonstration projects that develop collection technologies and / or uses for recycled or used lubricating oil."

[20] Sources for information on these programs come from the following locations:
* Operated under NYSERDA for varying time periods.
Sources:
CA – AQIP http://www.arb.ca.gov/msprog/aqip/aqip.htm
CA – ICAT http://www.arb.ca.gov/research/icat/icat.htm
CA – EISGP http://www.energy.ca.gov/research/innovations/
CA – TAP http://www.cleanairactionplan.org/programs/tap/default.asp
CA – UORDPG http://www.arb.ca.gov/ba/omb/farg/ombwfarg.htm#used
CO – CTDEF
http://www.leg.state.co.us/clics/clics2009a/csl.nsf/fsbillcont/97E2CDDCEF6F7B7787257537001A2EE6?Open&file=031_enr.pdf
CT – CCEF http://energy.gov/savings/connecticut-clean-energy-fund-ccef
CT – ODP
http://www.ctcleanenergy.com/YourBusinessorInstitution/FormerCommercialBusinessPrograms/TechnologyInnovationPrograms/OperationalDemoProgram/tabid/601/Default.aspx
CT – NETP http://energy.gov/savings/new-energy-technology-program
DE – GEF http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=DE01R
MI – XERDF
http://www.xcelenergy.com/Environment/Renewable_Energy/Renewable_Energy_Grants/Renewable_Development_Fund
NC – NCGBF http://www.nccommerce.com/scitech/grant-programs/green-business-fund
ND – REP http://www.nd.gov/ndic/renew-infopage.htm
NJ – EIGGF
http://www.njeda.com/web/Aspx_pg/Templates/Npic_Text.aspx?Doc_Id=1454&menuid=1509&topid=718&levelid=6&midid=1175
NY – NYSERDA http://www.nyserda.ny.gov/en/About.aspx
NY – NYSERDA: DOBBFSNY www.nyserda.ny.gov/-/media/Files/FO/Closed-Opportunities/2008/PON1195summary.pdf
NY – NYSERDA: IMCET www.nyserda.ny.gov/-/media/Files/FO/Closed-Opportunities/2012/PON2414summary.pdf
NY – NYSERDA: ACPT www.nyserda.ny.gov/-/media/Files/FO/Closed-Opportunities/2013/PON2569summary.pdf
NY – NYSERDA: ATT www.nyserda.ny.gov/-/media/Files/FO/Closed-Opportunities/2013/PON2781summary.pdf
RI – REF http://www.riedc.com/business-services/renewable-energy
TX – NTRD http://www.tceq.texas.gov/airquality/terp/ntrd.html

Program Name	State	Years	Purpose
Innovative Clean Air Technologies Program (ICAT)	CA	1993-2008	"ICAT was an Air Resources Board program from 1993 through 2008 that co-funded the demonstration of innovative technologies that could reduce air pollution. Its purpose was to advance such technologies toward commercial application thereby reducing emissions and helping the economy of California."
Air Quality Improvement Projects – AB 118 Advanced Technology Demonstration Projects	CA	2006-Present	"The purpose of the Advanced Technology Demonstration Projects is to help accelerate the next generation of advanced technology vehicles, equipment, or emission controls which are not yet commercialized."
Energy Innovations Small Grant Program	CA	1998-present	"The Energy Innovations Small Grant (EISG) Program provides up to $95,000 for hardware projects and $50,000 for modeling projects to small businesses, non-profits, individuals and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts. Research projects must target one of the PIER R&D areas, address a California energy problem and provide a potential benefit to California electric and natural gas ratepayers."

Program Name	State	Years	Purpose
Technology Advancement Program	CA	2007-present	“The Ports of Los Angeles and Long Beach have developed the Technology Advancement Program (TAP) to support development and demonstration of new, clean air technologies in the port environment.”
Clean Technology Discovery Evaluation Fund	CO	2009-present	Clean Technology Discover Evaluation Fund was created “for the purpose of improving and expanding the development of new clean technology discoveries at higher education research institutions”
Connecticut Glean Energy Fund	CT	2000-present	“The CCEF’s charge under the statute is to foster the growth, development and commercialization of renewable energy sources and related enterprises, and stimulate demand for renewable energy and the deployment of renewable energy sources, which serve end-use customers in the state.”

Program Name	State	Years	Purpose
Operational Demonstration Program	CT	2001-present	"The Clean Energy Finance and Investment Authority's (CEFIA) Operational Demonstration (Op Demo) Program provides financing to help technology innovators and entrepreneurs advance development and commercialization of emerging clean energy technologies."
New Energy Technology Programs	CT	2005-present	This grant program is designed to help small firms commercialize energy related technologies. Specifically, the program focuses on improving air quality, saving efficiency and growing Connecticut's economy.
Green Energy Fund	DE	1999-present	This program provides grants for the development and improvement of renewable energy technology. Is a part of Delaware's Green Energy Fund.
Xcel Energy's Renewable Development Fund	MI	2001-present	A grant program established in response to spent nuclear fuel being stored art Xcel's Prairie Island facility. "Grants support commercial technologies, and research and development."

Program Name	State	Years	Purpose
North Carolina Green Business Fund	NC	2008-2011	This program targets projects that develop green industry in North Carolina. Specifically, three target areas are defined: biofuel development and production, green building technologies and projects that promote the development of a green industry in NC.
North Dakota's Renewable Energy Program	ND	2007-present	"The Program's responsibilities include providing financial assistance as appropriate to foster the development of renewable energy and related industrial use technologies including, but not limited to, wind, biofuels, advanced biofuels, biomass, biomaterials, solar, hydroelectric, geothermal, and renewable hydrogen through research, development, demonstration and commercialization."
Edison Innovation Green Growth Fund	NJ	2011-present	"The EIGGF offers loans up to $2 million with a performance grant component to support technology companies with Class I renewable energy or energy efficiency products or systems that have achieved "proof of concept" and successful independent beta results, have begun generating commercial revenues, and will receive 1:1 match funding by time of loan closing."

Program Name	State	Years	Purpose
New York State Energy Research and Development Authority (NYSERDA)	NY	1975-present	New York State Energy Research and Development Authority. Created in 1975 focusing primarily on R&D to reduce New York's dependence on foreign energy.
NYSERDA – Development of Biofules, Bioproducts and Feed Stocks in New York State	NY	See NYSERDA	This program targets projects that "facilitate the development of innovative biomass feedstock technologies and bioproducts, including biofuels, biochemicals and other bioproducts"
NYSERDA – Innovation in Manufacturing of Clean Energy Technologies	NY	See NYSERDA	This program targets projects that "research, develop, demonstrate or commercialize an innovative energy-efficient manufacturing process for a Clean Energy Technology in New York State."
NYSERDA – Advanced Clean Power Technologies	NY	See NYSERDA	"NYSERDA seeks proposals to develop and demonstrate innovative renewable and other advanced clean power technologies, develop and demonstrate technologies that improve performance, or address and overcome specific barriers thwarting increased adoption of Eligible Technologies"

Program Name	State	Years	Purpose
NYSERDA – Advanced Transportation Technologies	NY	See NYSERDA	"NYSERDA seeks proposals to support development, demonstration, and commercialization of advanced transportation products, systems and services. Program objectives are to provide energy, environmental and economic benefits in New York State…"
Renewable Energy Fund Grants	RI	1996-present	Amongst other things, the Renewable Energy Fund support projects that "make electricity in a cleaner, more sustainable manner…" this includes research and development projects.
New Technology Research and Development	TX	2004-present	"The New Technology Research and Development Program (NTRD) provides financial incentives to encourage and support research, development, and commercialization of technologies that reduce pollution in Texas through the issuance of state funded grants."

Inclusion into Table 7 required that the program provide support for innovation that enhances sustainability. All incentive types (e.g., direct funding, tax credits) were considered; however, only programs that offered direct funding through grants and loans were discovered. The table does not include initiatives that targeted the adoption of environmentally technology (e.g., no-interest loans to install solar panels). Although adoption incentives play an important role in addressing the dual-market failure by increasing demand for environmentally friendly technology, their differences from the Fund limit potential insights. Additionally, programs that targeted only the development of facilities or infrastructure were excluded from the table.

Using information in Table 7, which summarized other state-level ST programs, the author undertook an exploratory investigation. The inclusion of a hazard model in the discussion of state-level adoption of sustainability technology (ST) programs follows the application of epidemic modeling presented in Geroski (2000) and Link and Scott (2003). Geroski overviewed multiple techniques that researchers have applied to the study of diffusion, including binary-outcome and epidemic models. Link and Scott used an analytical model to describe the growth of the Research Triangle Park (the Park) in North Carolina. Their rationale for considering growth of the Park as adoption of an innovation expressed in the following statement (p. 167):

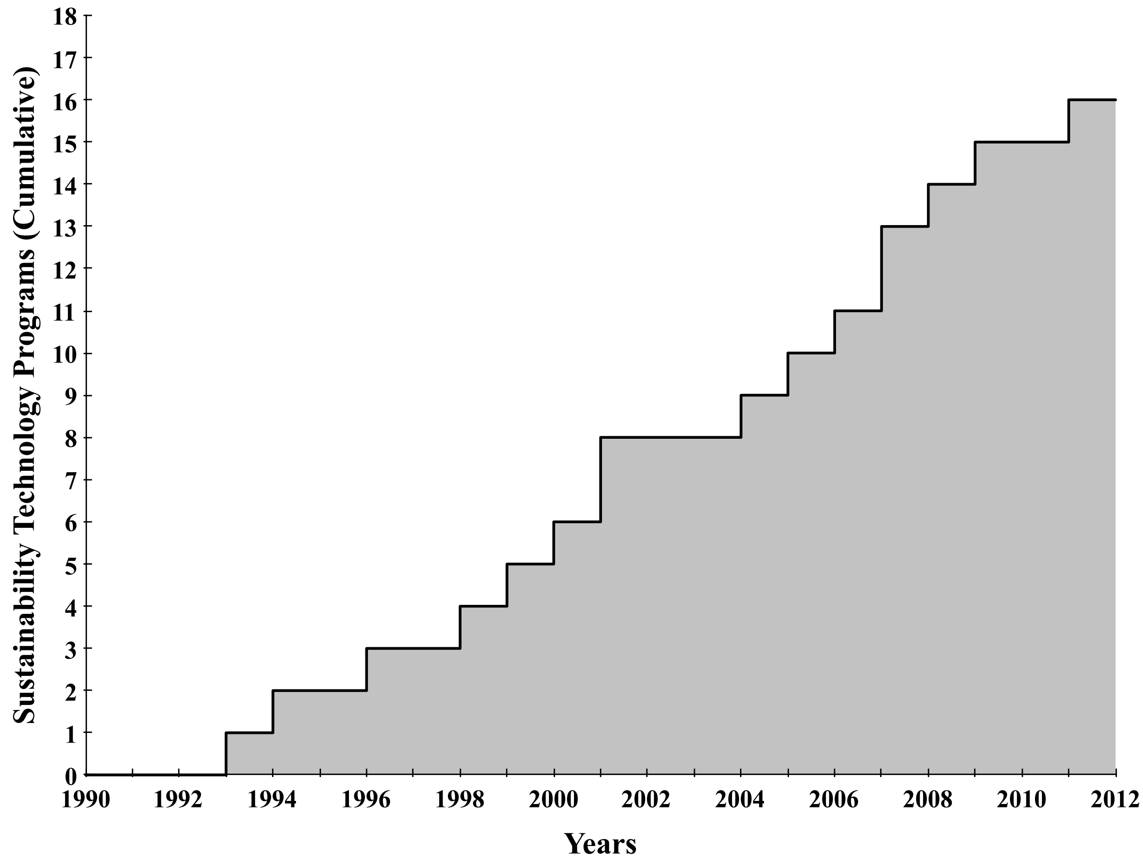
> The model is based on the hypothesis that the Park's growth can be thought of as the adoption of an innovation, where the innovation is the new innovative environment created by the Park and its infrastructure.

The adoption of a sustainability technology (ST) program by a state is considered to be an innovation, where the innovation is a new method of addressing market inefficiencies and promoting economic development in related industries. Following the precedent of previous authors, an epidemic model that examines the change in the rate of adoption over time is implemented. This model is merely descriptive in nature. Further analyses describing the determinants of policy adoption are left for future researcher.

Prior to the application of epidemic modeling, this section presents a series of figures shows the implementation of ST programs and the number of states that have adopted a ST program over time. Figure 6 shows the cumulative number of implemented ST programs over time. Figure 7 shows the ongoing ST programs. The vertical axis displays the number of programs and the horizontal axis indicates the year. NYSERDA is not included in the figure as it pre-dates the current trend in programs and can be considered an outlier. One can observe from both figures a relatively steady rate of program implementation with above average rates of adoption from 1998-2001 and 2004-2009. Two of the adopted programs have been discontinued, the first in 2008 and the second in 2011.

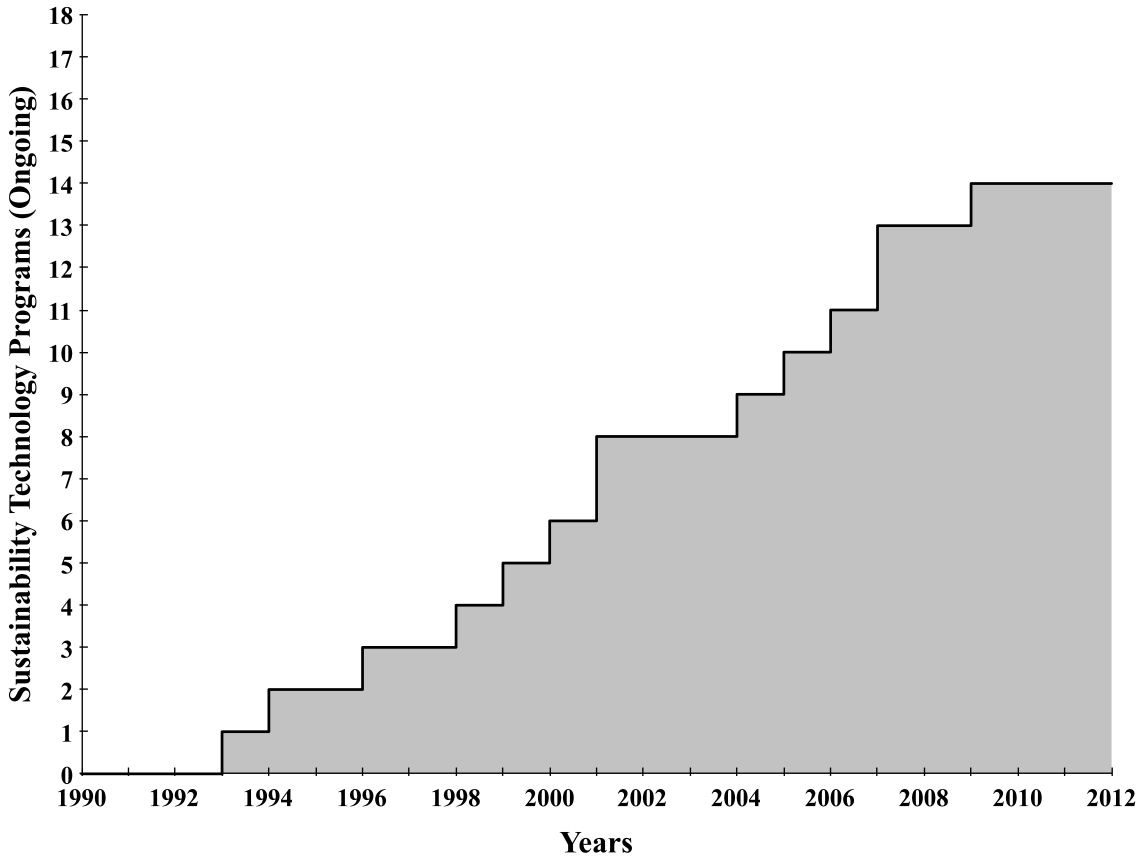
Figure 6 illustrates the cumulative number of state-level ST programs over time. The horizontal axis measures time in years from 1990 to 2012. The vertical axis counts the number of states that have implemented such a program. The first state-level ST program included in the figure was adopted in 1993. An increase in adoption can be observed in Figure 6 starting at 1993. Figure 7 follows a similar format to that of Figure 6, but depicts the number of ongoing ST programs for each year.

Figure 6. Cumulative Sustainability Technology Programs



To describe the rate of diffusion of ST programs, the author applied a Gompertz diffusion curve to the data on the adoption of ST programs over time. The choice of Gompertz follows from the rationale presented by Link and Scott (2003). The hazard, the probability of adopting a program conditional on not having already adopted one, was assumed to be monotonically increasing in time. A variety of factors support this assumption including the increased demand for green products and the increasing price of energy.

Figure 7. Ongoing Sustainability Technology Programs



The probability of a state having adopted an ST program at time t is given as F(t) in equation (1).[21] The probability of not adopting an ST program is given as S(t), the survival function in equation (2). In this model λ describes the baseline hazard and γ describes how the hazard changes over time. The sign of γ determines whether the hazard increases or decreases over time.

$$F(t) = 1 - S(t) \tag{1}$$

[21] Here, t indexes years and is normalized to be 0 in 1970.

$$S(t) = e^{(e^{-\lambda}/\gamma)(e^{\gamma t}-1)} \tag{2}$$

The hazard rate, the marginal probability of adoption conditional on not having adopted, is given as h(t) in equation (3).

$$h(t) = \frac{F'(t)}{1-F(t)} \tag{3}$$

Taking the derivative of the survival function in (2), it follows that

$$F'(t) = -S'(t) = e^{(\lambda+\gamma t)-(e^{-\lambda}/\gamma)(e^{\gamma t}-1)} \tag{4}$$

Substituting F'(t) into equation (3), it follows that h(t) can be written in terms of λ and γ.

$$h(t) = e^{(\lambda+\gamma t)} = e^{\lambda}e^{\gamma t} \tag{5}$$

Applying the Gompertz model to the data on state adoption of ST programs yields estimates for both λ and γ. The estimate of λ is -7.05 and the estimate of γ is 0.15.[22] The estimate for γ is positive, indicating the probability of adopting a ST program conditional on not having already adopted one is increasing over time.

Table 8 presents the estimated hazard rate for a series of years. One may calculate these estimated hazard rates by substituting the year (t) and the estimates for λ and γ into equation 5. The estimated probability of a state adopting an ST program in 1970 (t = 0),

[22] More precisely, λ is estimated to be -7.047569 and γ is estimated to be 0.1503056.

conditional on not already having one, was approximately .09%. This probably increased to approximately 35.5% for the year 2010 (t = 40).

Table 8. Estimated Hazard Rates of Sustainability Technology Program Adoption

Year	**t**	**h(t)**	**COA%**
1970	0	0.00086952	0.086952019
1975	5	0.001843589	0.184358912
1980	10	0.003908846	0.390884635
1985	15	0.008287682	0.828768169
1990	20	0.017571852	1.757185157
1995	25	0.037256495	3.725649451
2000	30	0.078992608	7.899260804
2005	35	0.167483071	16.74830712
2010	40	0.355103849	35.5103849

Determinants of Adoption

An exploratory exercise to investigate why some states have adopted such programs and other have not is presented here. State adoption of ST programs is hypothesized to be a function of the emphasis states place on investments R&D, especially on environmental- and energy-related R&D. The covariates considered are: state R&D intensity measured as relative R&D expenditures per dollar of Gross State Product (RD/GSP), its square ($(RD/GSP)^2$), and its log (ln(RD/GSP)); the presence of a DOE laboratory (DOELab); and the relative level of public support for environmental and sustainability technology as measured by the ratio of the budgets of all DOE laboratories in a state to Gross State Product (DOE/GSP), its square ($(DOE/GSP)^2$), and its log (ln(DOE/GSP)).[23] The analyses considered both linear and non-linear specifications of these variables.

Table 9 presents descriptive statistics and Table 10 presents a correlation matrix of these variables. Notably, one may observe a lack of a statistically significant relationship between the presence of a DOE lab and the relative level of state R&D expenditures to gross state product. This lack of a statistically significant relationship suggests that there is a not a strong relationship between states that heavily invest in R&D and the location of DOE labs.

Table 9. Descriptive Statistics of the Variables (n = 50)

Variable	Mean	Std. Dev.	Min	Max
Program	0.22	0.418	0	1
RD/GSP	1.033	0.877	0.121	5.193
$(RD/GSP)^2$	1.822	3.963	1.46E-10	2.70E-07
ln(RD/GSP)	-0.283	0.840	-2.114	1.647
DOE/GSP	16.434	60.576	0	375.258
(DOE/GSP)2	3866.162	20689.25	0	140818.4
ln(DOE/GSP)	-37.312	25.359	-52.959	5.928
DOELab	0.28	0.4535574	0	1

Note: *RD/GSP* is dollar of R&D expenditure per ten thousand dollars of Gross State Product. *DOE/GSP* is dollar of state-lab expenditure per ten thousand dollars of Gross State Product.

[23] These variables are ratios that have been calculated using nominal dollar values. The data are from 2009 expenditures, as reported by the National Science Foundation.

Table 10. Correlation Matrix of all Variables (n = 50)

	Program	*RD/ GSP*	*(RD/ GSP)^2*	*ln(RD/ GSP)*	*DOE/ GSP*	*(DOE/ GSP)^2*	*ln(DOE/ GSP)*	*DOE-Lab*
Program	1							
RD/GSP	0.0337	1						
(RD/ GSP)^2	0.1587	0.9083*	1					
ln(RD/ GSP)	-0.037	0.8629*	0.6052*	1				
DOE/ GSP	-0.1172	-0.1238	-0.0799	-0.1698	1			
(DOE/ GSP)^2	-0.0992	-0.1254	-0.0691	-0.1874	0.9625*	1		
ln(DOE/ GSP)	0.0892	-0.1405	-0.1247	-0.126	0.4669*	0.3274*	1	
DOE Lab	0.0989	-0.1389	-0.1239	-0.123	0.4394*	0.3027*	0.999*	1

Note: * indicates a 0.05 or better level of significance.

Table 11 presents the results of analyses using a Probit specification estimating the existence of ST programs in states. Robust standard errors are reported below each coefficient. Several model specifications were tested. The first three models include a dummy variable that indicates the presence of a DOE laboratory. The last three models include the measures of DOE laboratory budgets in the state relative to gross state product (DOE/GSP). These measures are included in a way that mirrors the inclusion of state R&D expenditures to gross state product (i.e., linear, quadratic and log).

Table 11. Probit Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
RD/GSP	0.069	-1.059*		0.023	-1.340*	
	(0.258)	(0.522)		(0.257)	(0.622)	
(RD/GSP)^2		0.267+			0.318$^+$	
		(0.103)			(0.120)	
ln(RD/GSP)			-0.043			-0.045
			(0.250)			(0.249)
DOELab	0.317	0.332	0.286			
	(0.440)	(0.455)	(0.437)			
DOE/GSP				-0.011	0.277	
				(0.010)	(0.191)	
(DOE/GSP)^2					-0.016	
					(0.013)	
ln(DOE/GSP)						0.004
						(.008)
Intercept	-0.940*	-0.307	-0.872$^+$	-0.721*	-0.117	-0.615
	(0.121)	(0.436)	(0.249)	(0.349)	(0.462)	(0.359)
Pseudo R^2	0.011	0.0929	0.0096	0.0257	0.1879	0.008
Wald Ratio (df)	0.54 (2)	10.06 (3)	0.5 (2)	1.27 (2)	11.62 (4)	0.42 (2)
Log psuedolikelihood	-26.06	-23.90	-26.09	-25.67	-21.39	-26.13

Note: * indicates significance at the 5% level. A $^+$ indicates significance at the 1% level.
N = 50.

The results in Table 11 suggest that the a quadratic relationship exists between the ratio of a state's R&D to GDP and the probability of that state establishing a program. Using the estimated coefficients from Model 2, one can calculate a threshold value of

1.98 dollars of R&D per thousand dollars of GSP. Above this value, increases in state R&D intensity lead to increases in the probability of adopting an ST program. Some possible explanations for this phenomenon include: a culture of awareness in states with optimal R&D intensity, policy makers seeking to leverage R&D capacity to promote economic growth, and R&D-intensive firms exerting influence on state legislatures.

The first potential explanation for this phenomenon is that a culture of awareness exists in states with the optimal levels of R&D intensity. The awareness described here can include concerns for sustainability as well as understanding of the positive externalities of innovative activity. This explanation suggests that policies that promote this culture of awareness may result in further diffusion of ST programs.

The second explanation for the observed relationship is that policy makers seek to leverage their state's competitive advantage in R&D to promote development in a sector they expect to grow. The Fund is an example of this explanation, evidenced in a statement about the purpose of the fund from the Board's Executive Director, John Hardin (2012):

> When then Lieutenant Governor Beverly Perdue proposed to the General Assembly the NC Green Business Fund her argument for it was that it would leverage North Carolina's economy by creating jobs through innovation, and it would also benefit the environment.

A third potential explanation to the observed relationship is R&D-intensive firms influencing policy makers to provide support for R&D. It is possible that R&D-intensive firms in states with R&D intensity above the threshold value have greater state-level political power. This political power could result in the state implementing relatively more R&D-promoting legislation such as an ST program.

Although all of these explanations are plausible, no concrete conclusions can be drawn from this analysis. Obtaining a more complete understanding of this phenomenon will require additional analyses that give careful consideration to the underlying diffusion process and employ a richer set of data.

Summary

This chapter overviewed North Carolina’s Green Business Fund by discussing its purpose and the particulars of its operation. Additionally, this chapter surveyed similar ST programs in other states. The existence of similar programs in other states suggests that understanding the impact of ST programs, such as the Fund, could be valuable to policy makers in North Carolina and elsewhere.

CHAPTER VI

PROGRAM EVALUATION LITERATURE

This chapter provides overview of the program evaluation literature. Here, Program evaluations refer to comparisons of the economic costs and benefits associated with publicly funded programs. Among other things, program evaluations are able to provide insight and guidance for future planning and management of programs. Two distinct literatures are considered in this chapter. The first literature relates to the traditional evaluation methodology pioneered by Griliches (1958), and later popularized by Mansfield, et al. (1977). The second literature relates to microeconometric-based studies that employ statistical methods to infer the relationship between public support and firm-level outcomes of interest.

Klette et al. (2000) expressed the benefits of combining the methods that underlie these literatures through the following statement (p. 482):

> Recent econometric advances suggest that it might be possible to estimate the distribution of the subsidy impacts across firms, but we believe that these methods should only provide a first step in a closer investigation of the economic benefitsof the most important innovations generated by the R&D subsidy programs. It would be useful to merge econometric studies of the kind discussed in this paper with more detailed case studies of the most successful projects, and perhaps also some of the less successful projects.

The Traditional Evaluation Methodology

Griliches(1958) and Mansfield, et al. (1977) provided the benchmark for traditional methodology program evaluation. In 1958, Griliches examined the costs and benefits of U.S. investment in hybrid corn and sorghum. To accurately capture the extent of the costs and benefits of this investment, Griliches included the full range of investment effects. He estimated the costs in terms of: direct expenses by the U.S. Department of Agriculture (USDA) and industry, increased expenditure on hybrid corn by farms, and lost per-bushel profits due to reduced prices. He estimated the benefits of the program in terms of profits from higher yields. Griliches used data from 1910 through 1955 to calculate both yearly and present-time costs and benefits of the government program.

Mansfield, et al. (1977) estimated social and private rates of return on innovations developed through private R&D investments. They examined 17 innovations and categorized each by innovation type, user type, and the industry in which the innovation was created. The authors found that the majority of the evaluated innovations yielded private rates of return lower than their respective social rates of return. Further, the others noted that for 30 percent of the innovations studied, while the investment was worthwhile to society, the private rate of return was so low that firms would not have undertaken the project if given perfect foresight. These innovations have the same social and private rates-of-return profile as Project A in Figure 2 in Chapter 2.

The Traditional Program Evaluation Literature

The traditional program evaluation literature focuses on estimating the economic impacts of investments in innovative activity. Link and Scott (2011b) provided a discussion of the traditional program evaluation literature as it relates to government investments in innovative activity. Table 12, drawing partially from Link and Scott, summarizes a portion of the traditional program evaluation literature related to evaluation of public-sector investments in innovative activity. The studies in Table 12 do not exclusively evaluate publicly funded and publicly performed innovative activity. For example, studies of the thermocouple calibration program (Marx et al., 1997), the standard references materials for sulfur in fuels program (Martin et al., 2000), the laser and fiberoptic power and calibration program (Marx et al., 2000) and the gas-mixture NIST traceable reference materials program (Gallaher et al., 2002a) evaluate services performed and products produced by NIST laboratories.

The studies listed in Table 12 employ a counterfactual method, attempting to predict what would have happened in the absence of these programs. The counterfactual method often employs data collected via detailed interviews of program participants. These interviews ask interviewees to compare realized outcomes with the counterfactual scenario in an effort to estimate the quantitative and qualitative benefits of the program. Using these estimates, researchers compute evaluation metrics to describe the benefits and value of the program. The remainder of this section discusses the evaluation metrics, quantitative benefits, and qualitative benefits in more detail.

Table 12. Evaluations and Findings[24]

Author	Year	Program	Findings
Griliches	1958	Public/Private Hybrid Corn Research (1910-1955)	NPV: $M468/$M902 B/C: 150/70-to-1 IRR: 35-40%
Mansfield, et al.	1977	Multiple Industrial/Commercial R&D Programs	SRR: 83%[25] PRR: 36%[26]
Marx, et al.	1997	NIST's Thermocouple Calibration Program	B/C: 2.95-to-1 IRR: 31.8%
Link	1997	Radiopharmaceutical Research	B/C: 97-to-1 IRR: 138%
Shedlick, et al.	1998	Alternative Refrigerants Research Program	B/C: 3.9-to-1 IRR: 433%
Marx, et al.	1998	Ceramic Phase Diagram Program	B/C: 10-to-1 IRR: 33.5
Gallaher and Martin	1999	IGBT Power Device Simulation Modeling	NPV: $6.5M-$13.4M B/C: 15.5-31.0-to-1 IRR: 67.4-85.6
Martin, et al.	2000	Standard Reference Materials for Sulfur in Fossil Fuels	NPV: $409M B/C: 113-to-1 IRR: 1056%

[24] Sources: National Institute of Standards and Technology (2012); Link and Scott (2012)
[25] SRR indicates the social rate of return. The value reported here is the average of all positive SRRs reported in the study.
[26] PRR indicates the private rate of return. The value reported here is the average of all positive PRRs reported in the study.

Author	Year	Program	Findings
Marx, et al.	2000	Laser and Fiberoptic Power and Energy Calibration Services	Calibration Services: NPV: $17.1M/ 23.8M/30.3M[27] B/C: 8.1/11.3/14.9-to-1 248NM Metrology: NPV (1990): $1.72M/2.55M/3.38M NPV (1999): $3.17M/4.69M/6.21M B/C: 2.3/3/3.8-to-1 IRR: 33.3%/43.1%/52% High Speed R&D and Metrology: NPV (1992): 10.9M.12.3M/13.8M NPV (1999): 17.5M/19.8M/22.1M B/C: 7.8/9.1/10.5 IRR: 119%/136%/155%
Leech	2000	Cholesterol Standards Program	NPV: $3.57M B/C: 4.47-to-1 IRR: 154%
Leech and Chinworth	2001	Data Encryption Standards Program	NPV (1973): $215M/$603M NPV (2000): $345M/$1190M B/C: 58/145-to-1 IRR: 267%/272%
Link and Scott	2001	Baldrige National Quality Program	NPV: 2.17B/24.65B[28] B/C: 18.2/207-to-1 IRR: 14.7%

[27] This format represents the low/medium/high range of estimates provided by the author(s).
[28] These are NPV of private/social benefits.

Author	Year	Program	Findings
Gallaher, et al.	2002c	Role-Based Access Control	NPV: $671.1M B/C: 69/109/158-to-1 IRR: 39%/62%/90%
Gallaher, et al.	2002a	Gas-Mixture NIST-Traceable Reference Materials Program	NPV: $49M/63M B/C: 21.4/27.2-to-1 IRR: 221%/228%
Gallaher, et al.	2002b	International Standard for the Exchange of Product Model Data in Transportation Equipment Industries	NPV: $1082M/$180M B/C: 11.4/7.9-to-1 IRR: 36.1%/31.6%
Link and Scott	2004	ATP's Intramural Research Awards Program	OFCom[29] References: NPV: $76M B/C: 267 IRR: 4400% ICBG[30]: NPV:$8B B/C: 5400-to-1 IRR: 230% IC for M[31]: NPV: $23M B/C: 33-to-1 IRR: 220% PCD for TFC[32]: NPV: $11M B/C: 7-to-1 IRR: 35%

[29] Optical Fiber Communcations
[30] Injectable Composite Bone Graphs
[31] Internet Commerce for Manufacturing
[32] Polymer Composite Dielectrics for Integrated Thin Film Capacitors

Author	Year	Program	Findings
Rowe, et al.	2008a	Investments in Superfilling Research	NPV: $2.242M/$6.428M B/C: 2.69/5.83-to-1 IRR: 43.4%/79.4%
Rowe, et al.	2008b	Low-k Materials Characterization Research	NPV: $3.93M/ $21.094M B/C: 2.54/9.25-to-1
O'Connor, et al.	2009	NIST's Combinatorial Methods Center	NPV: $118M B/C: 8.55-to-1 IRR: 161%
O'Connor, et al.	2010	DOE Photovoltaic Technologies	NPV: $5.724B/1.458B B/C: 3.24/1.83-to-1 IRR: 17%
Link	2010	Vehicles Technology Program, Subsection Advanced Combustion Engine R&D Program	NPV: $23.1B/42.6B B/C: 53/66-to-1 IRR: 63%
Gallaher, et al.	2010	Geothermal Technologies Program	NPV: $16.9B/6.4B B/C: 9.2/4.9-to-1 IRR: 22%

Evaluation Metrics

Table 12 notes the specific evaluation metrics that the author(s) employ: net present value (NPV), the benefit-cost ratio (B/C), and sometimes the internal rate of return (IRR).[33] The mathematical expressions for these metrics are below. For each

[33] Not all measures were reported by every evaluation, and some evaluations provide alternative measures such as the social rate of return and private rate of return.

expression: t represents time, B_t is the value of benefits at time t, C_t is the costs of the program at time t, n is number of time periods, and r is the discount rate.

Equation (1) gives the mathematical expression for NPV. NPV is sum of the discounted sum of benefits less costs for each time period. Equation (2) expresses the B/C, which is the ratio of present value of benefits to the present value of costs. The IRR of a program is the interest rate, *i*, which equates the net present value to zero. Equation (3) expresses the equation for IRR.

$$\text{NPV} = \sum_{t=0}^{t=n}\left(B_t \cdot (1+r)^{n-t}\right) - \sum_{t=0}^{t=n}\left(C_t \cdot (1+r)^{n-t}\right) \tag{1}$$

$$\text{B}/\text{C} = \sum_{t=0}^{t=n}\left(B_t \cdot (1+r)^{n-t}\right) / \sum_{t=0}^{t=n}\left(C_t \cdot (1+r)^{n-t}\right) \tag{2}$$

$$\text{IRR} = i \mid \text{NPV} = \left[\frac{B_0 - C_0}{(1+i)^0}\right] + \cdots + \left[\frac{B_n - C_n}{(1+i)^n}\right] = 0 \tag{3}$$

One should be cautious when comparing these measures across studies. Data limitations, the chosen discount rate, and the timing of evaluation affect the results of an evaluation. It may be that projects that appear to be better, as inferred from, say, a larger B/C, are in fact those that have more data available for analysis or those for which more time has elapsed so that more benefits have been realized. In addition to data limitations, not all of the projects listed use the same discount rate. Changing discount rates will change the present value of the streams of benefits and costs associated with projects, altering the calculated statistics.

Of all the evaluation metrics, NPV is the least comparable across studies. One reason for this limited ability for comparison is that the NPV of the program is dependent on the size of the program. The scale of benefits is often closely associated with the scale of the investment. To illustrate this point, consider the difference between the DOE's photovoltaic R&D (Department of Energy, 2010b) and NIST's Cholesterol Standards Program (Leech, 2000). The NPV of the photovoltaic R&D is nearly 1000 times that of the cholesterol standards program. This difference reflects the difference in scale of the projects but not in their success or failure. A better way to interpret the NPV is simply to examine if the present value of the program is positive or negative.

B/Cs and IRRs are more readily compared across programs but the caveats regarding discount rates and timing apply for both. If one is willing to assume comparable timing of benefits as well as discount rates, potentially a strong assumption, the studies may be compared to one another. The smallest benefit-cost ratio reported in the Table 12 was 1.83 for the DOE photovoltaic technology study. (O'Connor, et al., 2010) The largest benefit-cost ratio reported was 5400-to-1, attributed to the injectable composite bone grafts (ICBG) research program, part of ATP's intramural research program. (Link and Scott, 2004) Researchers reported IRRs for most of the evaluations listed. The smallest IRR reported was 14.7 percent, associated with the Baldrige National Quality Program. (Link and Scott, 2001) The largest IRR reported was the 4400 percent reported for optical fiber communications (OFCom) references program. (Link and Scott, 2004)

Quantifying Benefits

In an evaluation, researchers assign a dollar value to the benefits attributable to a program. All of the studies listed in Table 12 provide some measure of monetized benefits, which are used to calculate the evaluation metrics listed above. These quantified benefits can include: reduced costs through the avoidance of parallel R&D investments, increased producer and consumer surplus stemming from program outputs, and health and environmental benefits.

Programs realized benefits from reduced costs when the counterfactual scenario requires higher levels of funding to achieve the same results. Programs obtain these benefits most often when the program addresses an industry-wide problem. One such case was the search for alternative refrigerants. (Shedlick, et al., 1998) In this case, the federal government was able to produce a solution for industry with greater efficiency by avoiding wasteful parallel efforts and utilizing existing facilities. This greater efficiency resulted in benefits from reduced costs.

Increased production benefits are the monetized increases in producer and/or consumer surplus stemming from the program's output. The USDA's researcher on hybrid corn is one (Griliches, 1958). Another example is faster drilling times due to the enhanced drill bits developed from DOE research. (Gallaher, et al., 2010)

Measures of health and environmental benefits are often present when the program involved sustainability innovations. Examples of evaluations that include these benefits are: enhanced photovoltaic power systems (O'Connor et al., 2010), enhanced geothermal power systems (Gallaher et al., 2010), and programs to increase the energy efficiency of combustion engines (Link, 2010). The EPA's Co-Benefits Risk Assessment (COBRA) model, which provides estimates of environmental and health benefits, uses the quantity of reduced emissions due to increases in energy efficiency and the production of energy using non-fossil fuel technology as variables in.

Qualitative Benefits

Qualitative benefits are outcomes and outputs that are not readily assigned a dollar value. Most of the evaluations studies listed in Table 12 contain some form qualitative benefit. Measures of qualitative benefits include: knowledge benefits such as patent families and publications, strategic energy benefits such as reduced oil imports, and increases in employment.

Three DOE-sponsored studies in Table 12—Link (2010) O'Connor, et al. (2010), and Gallaher, et al. (2010)—contained detailed sections regarding qualitative benefits associated with the program in question. All of these studies included national-security improvements as a result of reduced usage of imported oil in their reported qualitative benefits.

Knowledge benefits were present in more evaluations than the afore-mentioned national-security benefits. Knowledge benefits are increases in public knowledge and are often expressed as new patents and publications that arise from the program. Researchers have qualified knowledge benefits through bibliometrics (e.g., citations and patent counts) and surveys.

Benefit Attribution

The attribution of benefits to a program or project is an important consideration when conducting an evaluation. The outcomes and outputs associated with a program may have relied on multiple input sources. Failing to account for inputs from other sources can bias the value of attributed benefits. Researchers can face difficulties determining the percentage of benefits that public support is responsible for if public and private parties jointly operate a project. One method to address this problem is to ask survey respondents about the specific contributions of the program to the observed results.

Researchers should ask questions to determine the appropriate counterfactual scenario for comparison. One possibility is a counterfactual in which the project would not have occurred in absence of program support. In this case, one may attribute the entirety of observed benefits to the program. A delay in the project's completion or a reduction in its quality is an alternative to the project not being undertaken. In this scenario, the counterfactual benefits can be the estimated as realized benefits discounted to account for the delay or proportionally reduced to reflect reductions in quality. The difference in realized and counterfactual benefits would then be attributable to the program.

Sensitivity

In the traditional evaluation literature, researchers conduct sensitivity analyses by employing alternative values for key variables in the calculation of benefits. An example of this can be found in the Leech and Chinworth (2001) study of Data Encryption

Standards where the assumed lag in absence of public support was varied from 3 to 6 years. A second example of sensitivity analysis is found in the Role-Based Access Control evaluation that used alternative measures of market penetration to evaluate low, medium and high levels of benefits (Gallaher, O'Connor, and Kropp, 2002).

Lessons from the Traditional Evaluation Literature

One can draw several conclusions from the body of work detailed in Table 12. In particular: the full measure of benefits from a program are not easily captures, the focus of the program often drives what benefits are included, and variation exists in the established framework for conducting evaluations.

First, one can conclude that it is often impossible to know the full economic impact of a program. Data limitations and questions about the true counterfactual epitomize this conclusion. Data limitations draw hard lines in terms of what researchers can calculate or estimate. Counterfactual ambiguity muddles the determination of the exact benefits a program provided and to what extent was a program solely responsible for them.

Second, one can conclude that program focus drives what types of benefits researchers should consider. Programs intended to provide industry-wide R&D solutions might best be measured in terms of avoided costs by firms. Programs that support sustainability innovation or other environmental concerns can result in benefits that include reduced oil usage, knowledge benefits from patented technologies, and health benefits from lower levels of pollution. However, this does not mean that researchers should ignore benefits in areas outside of a program's primary focus.

Third, one can conclude that variation exists in the established framework for conducting evaluations. Forms of variation include: the method by which researchers measure benefits, the benefits that researchers include, the appropriate counterfactual case, and how the researcher estimates the counterfactual. Data availability, program objectives, and other factors potentially influence the choices made. It is the job of the researcher to make informed decisions and to clearly state where and why these choices were made.

Statistical-Based Literature

In addition to the traditional evaluation methodology, researchers have examined the impacts of government intervention on the market for innovation using statistical-based methodologies. This section summarizes a pair of reviews of this literature, examines the techniques used, and details a collection of works from this field.

Overviews

This subsection overviews two reviews of the statistical-based literature pertaining to of public-support R&D. Of the studies covered in these reviews, the primary independent variables of interest were predominantly either subsidy receipt or the level of subsidy. Outcomes of interest included the quantity of privately funded R&D, the sales-to-R&D ratio, the creation of intellectual property, the survival of manufacturing plants, and increases in the level of employment.

Zuñiga-Vicente et al. (2012) reviewed the literature on the impact of public subsidy programs on private R&D investment. The authors reviewed 77 studies conducted during the time period of 1966 through 2011. Zuñiga-Vicente et al. found that the literature provided mixed evidence on the impact of public subsidies on private R&D expenditures (p. 25):

> The empirical evidence on the effectiveness of public subsidies is mixed and therefore inconclusive. Although results supporting the additionality hypothesis prevail, there are valuable contributions in favour of the substitution hypothesis and others that demonstrate a negligible effect.

Klette et al. (2000) reviewed microeconometric studies based on firm level data. They reviewed a group of five studies on the effect of government sponsored commercial R&D. In addition to their review of these five studies they also overviewed the estimation of counter factual outcomes using non-experimental data, and the identification of spillovers and social benefits of R&D projects. Klette et al. discussed two possible measures of spillovers. The first measure they discussed reflects the methodology presented in Section 6.2 and requires tracing the impact of innovations throughout the supply chain and estimating cost savings and benefits. The second measure discussed was the inclusion of some measure of industry knowledge in the production function to capture spillovers to other firms.

Techniques

Zuñiga-Vicente et al. noted that the many studies, especially the earliest considered, employed simple techniques to provide estimation of linear regression models, for which Ordinary Least Squares (OLS) served as the workhorse model. In addition to extensions of OLS, researchers employed non-linear techniques such limited dependent variables and maximum-likelihood estimation.

Studies presented in Zuñiga-Vicente, et al. employed both structural and non-structural models to examine the relationship between R&D support and firm-level outcomes. Researchers estimate production functions—a simple and common example of structural modeling—by assuming some functional form for the production function, providing some measures of inputs and outputs, and regressing one measure of a particular output those input measures. Researches also employed non-structural modeling techniques; possible reasons for employing non-structural modeling include: situations where estimating typical economic functions (e.g., production or demand) would not make sense, avoiding assumptions on functional relationships between variables, and following precedent set by previous works.

Unfortunately, researchers are often unable to observe allrelevant variables at all points in time. This limitation regularly persists in spite of extensive data collection efforts. As a consequence, researchers regularly estimate the counterfactual case. The estimation of the true counterfactual outcome is key to obtaining causally interpretable estimates. Discussion of the counterfactual and its estimation leads neatly into the discussion endogeneity inherent.

Endogeneity is a concern when examining the impacts of government R&D subsidies as it may lead to biased estimates. Endogenity can come from a variety of sources, one of which is selection bias. Selection bias can arise from a government agency choosing the firms to subsidize, firms self-selecting into programs, or possibly both. Researchers must address this endogeneity to determine the causal relationship between program participation and outcomes of interest. To this end, researchers have employed several statistical techniques that aim to remove endogeneity from their estimation of effects. Zuñiga-Vicente et al. list the methods of dealing with endogeneneity as: difference-in-difference estimators, sample selection, instrumental variables, and non-parametric matching. The papers overviewed by Klette et al. use difference-in-difference estimators to address endogeneity. They note that a drawback to difference-in-difference is the possibility of time varying factors to influence the selection and outcomes of firms.

In addition to difference-in-difference models, researchers have used matching, instrumental variables, and selection models to address endogeneity in studies. Each method has different data requirements and each addresses slightly different concerns. All of these techniques require data on firms that did not participate in the program. Matching techniques compare participating firms with non-participating firms, or groups of firms, and compare the differences in outcomes between the two. Selection techniques and instrumental variables use multiple stages of regression to estimate the impact of selection into the program via exclusion restrictions in the first stage. The difference in data requirements between matching and selection techniques stem from the fact that selection models require a variable that influences program participation but not the outcome of interest.

A Sample of Studies

The following is a discussion of a sample of evaluation studies. These studies illustrate the choices and considerations discussed above.

Griliches and Regev (1998) examined the impact of public support on firm performance. The authors estimated a production function that includes publicly funded R&D as an input, which is distinct from privately funded R&D. The authors were able to address the counterfactual issue by including data on non-subsidized firms into the estimation. Their findings suggest that the premium of government funded R&D to firms is particularly high.

Girma et al. (2003) examined the impact of government subsidies on plant survival and employment levels in the manufacturing sector of Ireland. Although not focused on R&D outcomes, the authors employed data that includes information on R&D-related subsidies and used techniques that were discussed above. Notably, the authors used matching and differences-in-differences to estimate the impacts of subsidies on firm-level outcomes of interest. They found that public support, including grants for technology and research, increase employment at the firm level.

Bérubé and Mohnen (2009) examined the effect of R&D grants on Canadian firms. They employed a matching technique to control for selection into grant receipt. Their findings suggest that Canadian firms that received both R&D tax credits and R&D grant funds were more innovative—introducing more new products and world-first products—than the firms who received only the R&D tax credit.

Lessons from the Statistical-Based Literature

The lessons learned from the statistical-based literature center on the methodological choices presented to the researcher. These choices depend on the goals of the research and the available data. The first lesson from this literature is that one must carefully consider the relationship they wish to estimate, as this will determine the appropriate statistical technique to be employed. Considerations that guide the choice of technique include economic theory, the nature of the dependent and independent variables, and the availability of data. The second lesson from the statistical-based literature is that one must consider the appropriate counterfactual case when using microeconometric techniques to estimate the impacts of public funds on firm-level outcomes. Statements of causal effects require addressing the potential for endogeneity and other forms of bias. Last, researchers should be explicit about the nature of their estimations, results, and any potential limitations.

Summary

This chapter overviewed two bodies of literature on program evaluation. The first body of literature used methods pioneered by Griliches (1958) to estimate the benefits of innovative activity and related programs. The second body of literature used statistical-based econometric techniques to estimate relationships between government interventions in the market for innovative activity on particular outcomes of interest.

Some overlap exists in the takeaways provided by these literature sets. Notably, both suggest that careful consideration should be taken when determining the appropriate counterfactual case. Examination of the traditional evaluation literature leads the researcher to key considerations of evaluations: not every impact of a program is readily observable, the benefits of a program are often driven by program focus, and that variation in the established framework of conducting evaluations. The statistical-based literature provides an understanding of the importance of determining appropriate estimation techniques and addressing endogeneity. These takeaways will influence the methodologies that will be employed in Chapters 8 and 9.

CHAPTER VII

OVERVIEW OF THE DATA

This chapter provides an overview of the data used to examine the Fund. The Board gathered data on Fund participants via a survey instrument sent to program participants. The overview below discusses the survey instrument, suggests possible uses to the responses of each section, and presents response summaries for each question. The survey instrument is presented in Appendix A.

Twenty found of the 27 Fund participants provided responses to the survey, yielding a 78% response rate. Three of the 24 respondents were public entities, two were operated by the state government and one operated by a local government. Data on all 24 respondents are presented below.

Survey Instrument for Green Business Fund Participants

The Board collected data on Fund participants through a survey, which it sent to all participants. This survey consists of 18 primary (i.e., first-stage) questions, some with follow-up (i.e., second stage) questions, divided into five categories. These categories are: Company Information, Project Status, Funding and Assistance, Outcomes and Overall Perception. Each primary question listed below is initially presented with its question number [#] from the survey. Follow-up questions are presented with the notation used in the survey which indicates the primary and follow-up question [#.#].

Company Info

The first section of the survey is Company Information. This section asks three questions relating to the company's manufacturing, revenue and employment. The first question [1] asks for the address and employment by category of the company's two largest manufacturing/work sites. The second question [2] asks for the company's total gross revenues for its most recent fiscal year broken into categorical ranges (e.g., $500,000-$999,999). The third question [3] of the Company Info section asks for the total number of employees by category at all sites.

The first and third questions of the survey ask about the number of employees at the company. The third expands upon the first by asking the company to include figures for all work sites. The survey directs companies to categorize employees into the following groups: professional/scientific, management, technical/technician, skilled labor, unskilled labor, and other. The survey asks companies to use full-time equivalence for the number of employees and provides the example "1 full time employee plus 1 half-time employee = 1.5 employees."

The responses to questions in this section provide data on the size of the firm in terms of employment and total company revenues. One may use these measures as controls for company size. Additionally, one might explore variations in the mix of employee categories across companies.

Table 13. Summary Statistics of Total Employees at All Facilities [3]

	Obs.	Mean	Std. Dev.	Min	Max
Professional/Scientific	24	13.96	24.52	0	91
Management	24	3.83	7.04	0	35
Technical/Technician	24	5.75	15.72	0	78
Skilled	24	4.46	9.93	0	40
Unskilled	24	1.00	2.38	0	10
Other	24	13.13	57.76	0	284
Total	24	42.13	100.78	0	501

Project Status

The Project Status category has one question that requires a response and second question that is conditional on the response to the first. The first question [4] asks for the current status of the supported project. Possible responses include the project has been discontinued, the project's R&D is still underway, the project is being commercialized, and the project is complete and in use by the target market segment.

Table 14. Project Status Response Counts [4]

Status	N
Discontinued	5
Still in development	7
Commercialization in process	7
In use by target audience	5

Conditional on the discontinuation of the project, a second question [5] asks for the reason(s) for discontinuation. Possible responses to this second question include: technical failure, insufficient market demand, loss of the principal investigator, changes in company priorities, lack of project competitiveness, achieving the project goal, or licensure of the product to another company.

Table 15. Reason for Discontinuation Response Counts [5]

Reasons	N
Technical Failure	2
Demand Too Small	1
Technical Risk Too High	2
Not Enough Funding	3
Company Shifted Priorities	1
Principle Investigator Left	1
Other Reason	1

Responses to questions in this section provide information on the progress, completion, or failure of projects receiving support. This discussion will consider two uses of these data. First, one may use these data as dependent variables in econometric models testing the impact of inputs and company characteristics on project success. Second, one may use these data as control variables in econometric analyses that examine other outcomes of interest.

Funding & Assistance

The survey section titled Funding and Assistance asks a series of questions regarding outside funding for the project and inquires about partnerships with outside entities. This section contains three primary questions, each with one or more follow-up questions conditional on the primary response.

The first primary question [6] asks for the approximate total of additional R&D funding from the private sector, the public sector and other sources. Following this question, the survey asks [6.2] participants to agree or disagree to a statement that grant receipt helped the organization receive funding from one of the listed sources, using a seven-point Likert scale. The survey directs the participants to respond neutral if the response to the primary question was zero or unknown.

Table 16. Summary Statistics of Outside Funding [6]

	N	Mean	Std. Dev.	Min	Max
Other Domestic Private Company	24	177416.7	814727.6	0	4000000
Other Private Equity	24	6250	22421.36	0	100000
Personal Funds	24	53333.33	205879.2	0	1000000
US Venture Capital	24	250000	1032094	0	5000000
Own Company, Inc. Borrowed	24	19852.71	50352.56	0	200000
SBIR/STTR Funds	24	10416.67	36053	0	150000
Non-SBIR Federal Funds	24	107104.2	509887.4	0	2500000
Other State Funding	24	7666.67	26081.26	0	100000
College or University	24	416.67	2041.24	0	10000
Foreign Direct Investment	24	0	0	0	0
Non-Profit	24	0	0	0	0
Total Non-GBF Funding	24	632456.90	1622532	0	6500000

Table 17. Grant Helped Obtain Outside Funding Response Count [6.2]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	11
Slightly Agree	4
Moderately Agree	0
Strongly Agree	9

The second question [7] in the Funding and Assistance section asks if there was involvement with university/college faculty, students, facilities, or equipment in the project. This question has four follow-up questions. The first follow-up question [7.2] asks if the grant receipt enhanced the scope or quality of the partnership noted in the question using a seven-point Likert scale. If the response to the first follow-up question was one of the agree choices, the second follow-up question [7.3] asked if any of the universities or colleges were based in North Carolina. The survey asked [7.4] participants answering affirmative to collaborating with universities based in North Carolina to list the universities or colleges. The final [7.5] follow-up question asked if this partnership has led to, or will likely lead to, additional partnerships with the university or college in question.

Table 18. University Involvement and Future University Partnerships [7] & [7.5]

	Yes	No
University Involved	12	12
Future Partnership	11	1

Table 19. Grant Helped Partnership with University or College [7.2]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	1
Slightly Agree	0
Moderately Agree	2
Strongly Agree	9

The third and final question [8] in Funding and Assistance section asks if there was collaboration on the supported project with outside companies or non-profits. The follow-up questions [8.2] through [8.5] to this primary question were identical to those regarding university collaboration, but asks about collaboration with companies or non-profits.

Table 20. Partner Involvement and Future Partnerships [8] & [8.5]

	Yes	No
Partner Involved	6	18
Future Partnership	6	0

Table 21. Grant Helped Partnership [8.2]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	0
Slightly Agree	1
Moderately Agree	1
Strongly Agree	4

These responses provide data on inputs into the R&D process. The first question provides information on additional costs to be included in the calculation of producer and consumer surplus. All three primary questions in this section provide data that can be used to estimate the relationships of inputs and the outcomes of supported projects in econometric models.

Outcomes

The Outcomes category focuses on the creation and retention of jobs, intellectual property creation and sales/licensing revenues. There are six primary questions in this section. Each question is specifically and carefully worded to direct respondents to consider only the supported project and the impacts of grant receipt.

The first question [9] of the Outcomes section asks how many jobs, by category, were created by grant receipt, and how many jobs, by category, were retained by grant receipt. The potential job categories and instructions with regard to full-time equivalence are the same as those detailed in the Company Info section.

Table 22. Jobs Created by Category [9]

Category	N	Mean	Std. Dev.	Min	Max
Professional/Scientific	24	0.46	0.51	0	1
Management	24	0.17	0.38	0	1
Technical/Technician	24	0.71	1.37	0	5
Skilled	24	0.96	2.58	0	11
Unskilled	24	0.00	0.00	0	0
Other	24	0.17	0.56	0	2
Total	24	2.46	4.04	0	16

Table 23. Jobs Retained by Category [9]

Category	N	Mean	Std. Dev.	Min	Max
Professional/Scientific	24	0.67	1.27	0	6
Management	24	0.33	0.76	0	3
Technical/Technician	24	0.38	0.77	0	3
Skilled	24	0.54	1.56	0	6
Unskilled	24	0.25	1.03	0	5
Other	24	0.33	1.17	0	5
Total	24	2.50	5.22	0	23

The second question [10] in the Outcomes section asks the participant to give the number of patents and/or copyrights for the technology developed as a result of grant receipt. Additionally, the participant is asked to provide estimated lifetime value of the intellectual property. The survey directs the participant to respond to these questions by categorizing intellectual property into four groups: patents applied for but pending, patents received, copyrights applied for but pending, and copyrights received.

Table 24. Intellectual Property Creation [10]

Category	Count	Value
Patent(s)	2	$0
Patent(s) Pending	9	$80,000,000
Copyright(s)	0	$0
Copyright(s) Pending	3	$505,000

The third and fourth questions in the Outcomes section ask about sales and licensing revenues from technologies developed during the supported project. The third question [11] asks if the participant has had any sales or revenues from technology developed during the project. The survey asks for categorical responses to this question using the following categories: no sales to date but the project outcome is in use by the intended target; no sales to date and no future sales expected; no sales to date but future sales expected; sales of products, processes, or services; other sales such as rights or spin-off companies; and licensing fees. The fourth question [12] in this section asks for the total value of products, processes, or services derived from the project from both own sales and licensing revenues. Following this question, the survey asks respondents [12.2] to provide a seven-point Likert response to a statement that grant receipt made these sales possible.

Table 25. Status of Sales [11]

Response	N
No sales to date but in use by intended target	4
No sales to date, none expected	7
No sales to date, future sales expected	7
Sales of product(s), process(es), or service(s)	8
Other sales	1
Licensing fees	0

Table 26. Sales to Date [12]

Category	N	Mean	Std. Dev.	Min	Max
Own Sales	24	796312.50	3463230.00	0	17000000
Licensee Sales	24	12500.00	61237.24	0	300000

Table 27. Grant Helped Sales [12.2]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	15
Slightly Agree	0
Moderately Agree	3
Strongly Agree	6

The fifth question [13] in the Outcomes section of the survey asks respondents to provide their expected total sales during the calendar year 2012 resulting from technology developed during the supported project. The survey directs the respondents to list expected sales in two categories: expected sales of products, processes, or services; and expected licensing revenues from rights to technologies, spin-off companies, or other sources. A follow-up question [13.2] asks firms to provide a seven-point Likert response to a statement that grant receipt helped yield one or more type of expected sales.

Table 28. Expected Sales in 2012 [13]

Category	N	Mean	Std. Dev.	Min	Max
Expected Sales, Own	24	648958.30	2090201.00	0	10000000
Expected Sales, Licensee	24	45208.33	162075.40	0	750000

Table 29. Grant Helped Expected Sales [13.2**]**

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	13
Slightly Agree	1
Moderately Agree	4
Strongly Agree	6

The sixth and final question [14] of the Outcomes section asks participants what percentage of their revenue growth from the time of grant receipt until present would they attribute to support from the Fund. The survey asks for responses to this question to be given as the following categories: 0 to 24 percent, 25 to 49 percent, 50 to74 percent, and 75 percent or more.

Table 30. Growth Attributable to the Fund [14]

Growth Percentage	N
< 25%	15
25-49%	6
50-74%	2
>75%	1

The responses to this question provide data on the outcomes of the supported projects. The revenues from sales and licensing provide information that one can use to estimate producer and consumer surplus. Econometrically, once can use these data as dependent variables in regressions. The intellectual property responses in particular can be used to estimate IP production functions.

Overall Perceptions

The final section of the survey, Overall Perceptions, asks four questions about the grantee’s perception of the impact, effectiveness, and efficiency of the Fund. All four questions ask for seven-point Likert responses to statements. The final two also ask respondents for additional comments.

The first question [15] of the Overall Perceptions section asks the company to respond to a statement that the Fund increased the intensity and quality of the company’s R&D efforts. The second question [16] asks for a response to a statement that the Fund helps encourage the expansion of small to medium sized businesses that have innovative commercial technologies, products, and services to grow in North Carolina.

Table 31. The Fund Increased Intensity and Quality of R&D [15]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	2
Slightly Agree	2
Moderately Agree	7
Strongly Agree	13

Table 32. The Fund Encourages Growth of Small-to-Medium Sized Businesses [16]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	0
Slightly Agree	2
Moderately Agree	5
Strongly Agree	17

The third question [17] of the Overall Perceptions section asks for a response to the statement that the Fund is an effective program. The fourth and final question [18] asks for a response to the statement that the fund is efficiently managed. These final two questions ask for additional comments and ask if these additional comments may be shared with the NC General Assembly.

Table 33. Fund is an Effective Program [17]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	0
Slightly Agree	2
Moderately Agree	3
Strongly Agree	19

Table 34. Fund is Efficiently Managed [18]

Response	N
Strongly Disagree	0
Moderately Disagree	0
Slightly Disagree	0
Neutral	1
Slightly Agree	1
Moderately Agree	5
Strongly Agree	17

The responses to the Overall Perceptions section provide some insight into perceived effectiveness and efficiency of the Fund. One can use data from these responses to examine correlations between perceived effectiveness and measures of inputs and outputs, the production of intellectual property, and estimates of producer and consumer surplus.

Notes on Additionality

The issue of additionality must be taken into account to ensure that results from the analyses provide an accurate measure of benefits attributable to the Fund. Here, additionality is interpreted to mean “the extent to which something happens as a result of an intervention that would not have occurred in the absence of the intervention" (English Partnerships, 2008, p. 3). This definition makes additionality analogous to the difference between the observed and counterfactual outcomes as discussed in Chapter 6.

Here, the specific wording of the survey instrument addresses the issue of additionality. Survey question [12] asks for the value of sales from the projects supported by the Fund, the wording for this questions is:

> For your company and/or your licensee(s), what is the approximate dollar amount of total sales resulting from the technology developed during this project? If multiple grants (from other sources) contributed to the ultimate commercial outcome, *report, to the extent possible, only the share of total sales appropriate to the project supported by this NC Green Business Fund Grant*. [Emphasis added]

Note that underlined portion of [12] instructed respondents to report only the share of total sales from projects supported by the Fund. As such, one may assume the reported figures for sales and other pecuniary outcomes reflect only the benefits that are attributable to participation in the Fund.

Summary

This chapter overviewed the survey instrument from which data on Fund participants was collected. Chapter 8 presents the results of the application of an evaluation to these data. Chapter 9 explores the impacts of the Fund through empirical econometric analyses.

CHAPTER VIII

APPLICATION OF THE EVALUATION MODEL

One of the legislative objectives of the Fund is to help grow a green economy in North Carolina.[34] Toward that end, the total surplus generated from projects supported by the Fund can be taken as the resulting growth associated in the green industry. Thus, a benefit-to-cost analysis that compares the value of this surplus to the cost of the Fund provides one measure of success. That is to say, did the benefits resulting from the Fund outweigh its cost and therefore result in growth in the green industry that was larger than the state's investment (i.e., positive net surplus)? This question then allows the success of the Fund to be defined as a benefit-to-cost ratio greater than one.

Benefit-to-cost analysis is one of the tools that economists employ to examine the impacts of policy as discussed in Chapter 6. In a review of the policy evaluation literature, Anthoff and Hahn (2012) extolled the contribution of benefit-to-cost analysis, and suggested that conducting differential analyses on different policies can lead to the implementation of more efficient policy. They further expressed their view about benefit-to-cost analysis as (p.217):

> Such work is generally not glamorous and does not typically have a high pay-off for academics because it rarely breaks new theoretical ground. It can, however, raise the cost to politicians and regulators of pursuing

[34] This chapter draws directly from Hall (2015).

> inefficient regulations by making these costs more transparent. We believe that more of this research should be encouraged by foundations, governments, and the private sector.

Like other facets of applied economic research, the appropriate tools for conducting benefit-to-cost analysis are driven by theory, data, and practical considerations. This chapter refines one such tool that is available to researchers conducting benefit-to-cost analysis, namely a novel implementable model for comparing social benefits to social costs.

This chapter presents the application of the evaluation model and the findings from that application. The remainder of this chapter is as follows. Section 8.1 presents the description of the economic model used in this examination. Section 8.2 summarizes the data used in this examination. Section 8.3 presents the application of the model to the data. Section 8.4 summarizes the chapter and presents potential inferences that one may draw from the results of this examination.

Description of the Model

The examination of public policies through the lens of benefit-to-cost analysis is a cornerstone of economic research. Stigler (1965, p. 2) articulated this view nearly five decades ago:

> The basic role of the scientist in public policy, therefore, is that of establishing the costs and benefits of alternative institutional arrangements. [Adam] Smith had no professional right to advice England on the Navigation Acts unless he had evidence of their effects and the probably effects of their repeal. A modern economist has no professional right to advise the federal government to regulate or deregulate the railroads unless he has evidence of the effects of these policies.

Additionally, as previously noted, Anthoff and Hahn extolled the contribution of benefit-to-cost analysis to improve the efficiency of public policy. Indeed, many public and private organizations use some form of benefit-to-cost analysis to examine policy decisions and inform future choices.

One method economists use to conduct benefit-to-cost analysis involves an economic model to calculate the changes in total surplus attributable to a program. This change in surplus is compared to costs to determine the program's benefit-to-cost ratio. An example of this method is in The World Bank's (1995, 2006, 2008) collection of evaluations of rural electrification projects. The World Bank gathered data on the price and quantity consumed of electricity before and after the electrification projects. Using these data, The World Bank was able to calculate the increase in total surplus derived from these projects. The World Bank's model assumes an isoelastic demand specification, which conforms to what they determine as (2008, p.134) "best practice."

The model developed here examines the total surplus attributable to a publicly-funded technology program. To do so, the total surplus of a program, conditional on the elasticity of demand for the innovations, is compared to cost of operating the program. The model yields a calculated elasticity of demand below which the benefit-to-cost (*B/C*) ratio of the program is greater than one (in absolute value). That is to say, if the actual elasticity of demand is lower than the calculated value, the program's social benefits will be greater than its costs. Therefore, calculated elasticities of demand that are relatively large provide stronger support that the benefits of a program outweigh the costs.

The model relies on several assumptions. First, the model assumes that the firm develops from funded R&D a unique technology so that it has or will have, at least temporarily, a market advantage.[35]

Second, the model assumes that there may in fact be existing substitute technologies that perform similar functions. The potentially existing technologies are considered to be goods that provide outputs that are similar to the developed technology but are not necessarily more simplistic versions of it.[36, 37]

And, third, the model assumes that the firm faces an isoelastic demand for its technology and has a constant average and marginal cost.[38] Fixed costs are assumed to have occurred during the research and development phase of the product cycle.

Assume the firm faces an isoelastic demand expressed as[39]:

(1) $$x = ap^{-\varepsilon}$$

---

[35] The assumption of market advantage (i.e., monopoly power), even if temporary, creates deadweight loss. If the assumption of market advantage were to not hold, the total surplus would be greater than what the model suggests.

[36] Automobiles and horse-drawn carriages are an example of reasonable substitutes as both provide transportation but do so with different technologies.

[37] The presence of an existing technology would mean that the model should account for the change in, not merely the size of, total surplus. Thus, the surplus attributable to the Fund (below) is truncated from above by the price of the existing technology so that only this change in total surplus is included.

[38] This model is an extension of a more simplistic evaluation model developed by Allen, Layson, and Link (2012) (the A/L/L model) that assumes the innovating firm faces a linear demand function in an environment with no substitute technologies. This paper extends the A/L/L model to an isoelastic demand function and it allow for the inclusion of an existing technology. These changes serve two purposes: first, to more closely align the model with methods used elsewhere (e.g., The World Bank) by considering the change in net surplus; and second, to allow researchers to bring more data to bear in the analysis (i.e., the relative price of an existing technology). See Hall (2015) for a detailed discussion and implementation of the A/L/L model.

[39] Isoelastic demand imposes a functional form with a constant elasticity of demand. Other specifications, such as linear in Allen, et al. (2012) may be used. However, the isoelastic demand is useful as it allows for the inclusion of an existing substitute technology without imposing nuisance (i.e., extraneous) parameters.

The terms in equation (1) are defined as follows: x is the quantity demanded and p is the price of the developed technology; ε is the own-price elasticity of demand, which is assumed to be greater than one; and a is a constant.[40]

Total surplus (*TS*) is the sum of producer surplus (*PS*) and consumer surplus (*CS*). Producer surplus (i.e., profits) are defined here to be $(p - c)x$. Where c is the constant marginal cost of production. By applying the inverse elasticity rule, one can express producer surplus as the value of revenues divided by the elasticity of demand. This condition is expressed as:

(2) $$PS = \left(\frac{1}{\varepsilon}\right)(p^* x^*)$$

Where p^* and x^* are the firm's profit-maximizing price and quantity, respectively.

Consumer surplus is defined to be the area under the demand curve above the price. This area, assuming no existing substitute technologies, is expressed as the following integral:

(3) $$CS = \int_{p^*}^{\infty} a p^{-\varepsilon} dp$$

This integral can be simplified and yields the solution:

(4) $$CS = [1/(\varepsilon - 1)](p^* x^*)$$

---

[40] The assumption that ε is greater than one is required for the model to result in a plausible solution. Specifically, if a monopolist faces a demand that is inelastic (i.e., $\varepsilon < 1$) then an increase in price will result in an increase in total revenues. Given a constant marginal cost, the profit-maximizing monopolist will charge an infinite price. Thus, equation (2) and the subsequent results no longer hold.

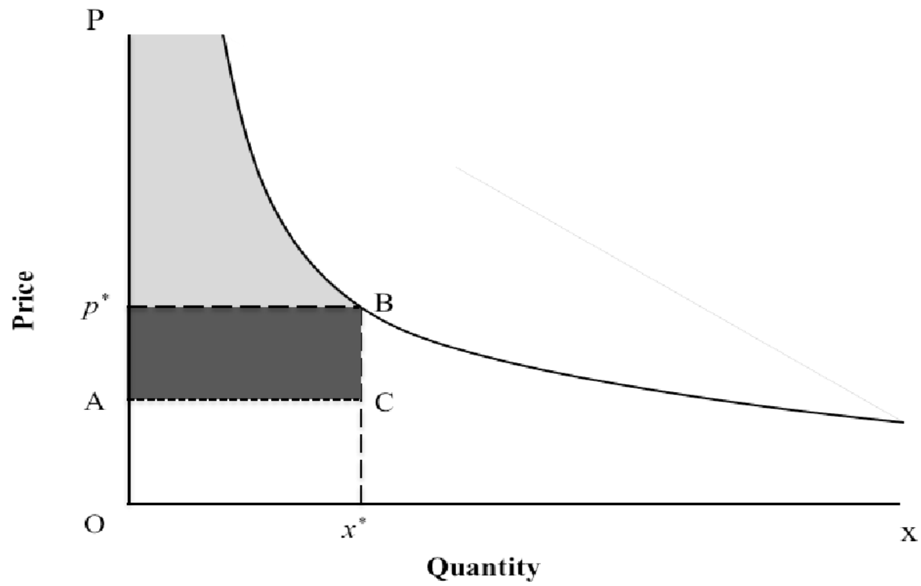
Finally, total surplus, the sum of consumer and producer surplus, is:

(5) $$TS = \left[\frac{1}{\varepsilon - 1}\right](p^* x^*) + \left(\frac{1}{\varepsilon}\right)(p^* x^*)$$

Total surplus is viewed here to be the benefits to society. With specific reference to the evaluation of the Fund, one is able to calculate the value of ε that yields a *B/C* equal to one by setting equation (5) equal to the fixed costs of the program and solving for ε. The value of ε for which *B/C* = 1 is denoted as ε^*. Again, if the true value of ε is less than ε^* then the social benefits of the program are greater than costs (i.e., *B/C* > 1).

Figure 8 illustrates the model assuming no existing substitute technology. The solid line is the demand in absence of a substitute. Note that equation (1) gives the functional form of demand. From Figure 8, total revenue is the area ($0p^*Bx^*$); the darker shaded portion of the total revenue area is producer surplus (cp^*BC), an area proportional to total revenue, as expressed in equation (5), by the amount $(1/\varepsilon)$. The lighter shaded area, between the vertical axis and the demand curve and above the line segment (p^*B), depicts consumer surplus. The total surplus of the innovation is the combined areas of the two shaded regions.

Figure 8. Graphical Illustration of the Evaluation Model without a Substitute Technology



The existence of a substitute technology can be included in the model. This inclusion is done by assuming that some existing substitute technology (ET) is sold at a price p_{ET}, where $p_{ET} > p^*$. This relationship between own and existing technology price can be maintained if innovators are assumed to enter the market only if they are able to exert a market influence. Given the existence of a substitute technology, the demand curve is now considered to be horizontal (i.e., truncated from above) at p_{ET}, and it follows its original form at all prices below p_{ET}. For convenience, the ratio of p_{ET}/p^* will be expressed as m, which is always greater than one. Additionally, the relationship $p_{ET} = mp^*$ is used to simplify notation below.[41]

---

[41] It is possible to that the model may yield plausible results (i.e., non-infinite price) if ε is less than one when an existing substitute technology is present. The profit-maximizing monopolist will not charge a price greater than p_{ET} as the quantity demanded is zero at any price higher than this. The new price will be p_{ET}, and the quantity demanded will be $ap_{ET}{}^{-\varepsilon}$. However, equation (2) would no longer hold for the value of *PS.* Thus, implementation of this specification is not feasible given the current data limitations.

The addition of an existing substitute technology conforms with the methods used by The World Bank by limiting the calculation of social benefits to only the change in total surplus. This inclusion does not alter the value of producer surplus from equation (2), as the producer maintains a market advantage. However, the value of consumer surplus is now zero at all prices above p_{ET}. The integral that expresses the value of consumer surplus given the existence of a substitute is:

(6) $$CS = \int_{p^*}^{mp^*} ap^{-\varepsilon}dp$$

This integral simplifies to the expression:

(7) $$CS = [1/(\varepsilon - 1)](1 - m^{1-\varepsilon})(p^*x^*)$$

Thus, the value of the change in total surplus under the assumption that an existing technology is present is expressed as:

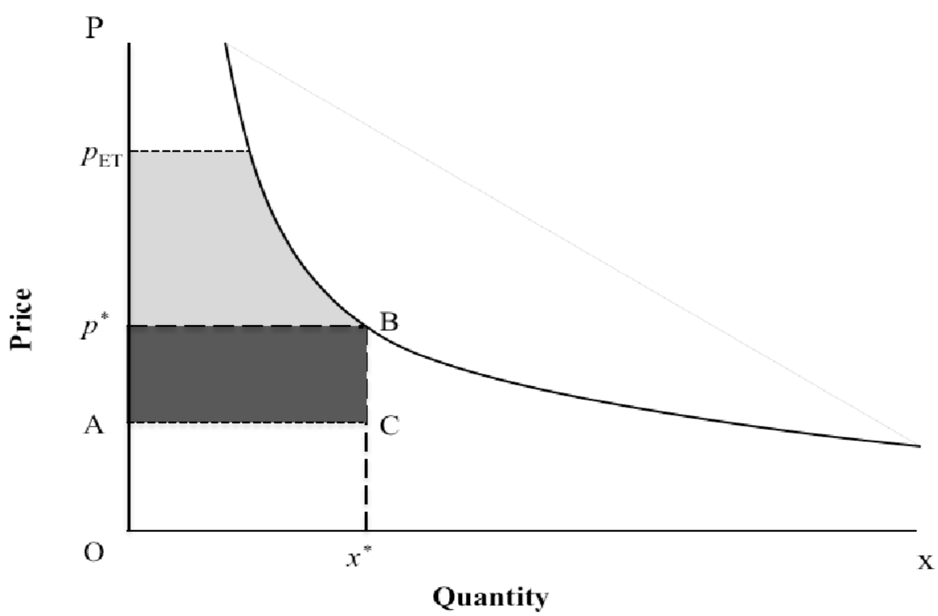
(8) $$TS = (1/\varepsilon)(p^*x^*) + [1/(\varepsilon - 1)](1 - m^{1-\varepsilon})(p^*x^*)$$

The value of ε^*, with a known or assumed value of *m*, can be calculated by setting equation (8) equal to the fixed costs of the program and solving for ε^*. Given the complex nature of equation (8), an analytical solution for this ε^* is not easily obtained.

However, one may employ an iterative process to determine the value of ε^* for a given value of m.[42]

Figure 9 shows how substitutes affect the model with a substitute technology. The horizontal dotted line at p_{ET} depicts the existing technology that is more expensive than the newly developed technology. Demand is now zero for all values of p above p_{ET}. The altered demand curve is horizontal at p_{ET}, and follows its original path for all values of $p < p_{ET}$. Thus, p_{ET} and therefore *m* serve to attenuate the quantity of *CS* that is included in the calculation of *TS*. For a given value of the elasticity of demand, ε, the value of *CS* increases as *m* increases.

Figure 9. Graphical Illustration of the Evaluation Model with an Existing Substitute Technology



[42] The process used herein is as follows. The author calculated the value of *B/C* starting with a value of ε = 1.01 and then at values of ε incrementally increased by .01. The process is repeated until the calculated value of *B/C* is greater than or equal to 1. The largest value of ε for which *B/C* < 1 is reported to be ε^*.

Summary of Data used in the Model

The survey results contain data on the revenues and fixed costs associated with each funded project. Respondents were requested to report these revenues and fixed costs stemming only from the projects supported by the Fund. The survey does not include information on either the price of the developed technologies or innovations, or the quantities sold. This lack of market information leads to the choice of an evaluation model that relies only on information pertaining to revenues and fixed costs of development. Table 35 outlines the available data on revenues and fixed costs, adjusted for inflation to 2012 dollars, associated with the projects supported by the Fund. The revenue data in Table 35 pertain to the 24 responding projects and the fixed costs data pertain to all 27 funded projects.[43]

Table 35. Descriptive Statistics on Benefit and Cost Category Variables ($2012, 1000s)

Category	Mean	Std. Dev.	Min	Max	Total
	Own and Licensee Sales (n=24)				
To-Date Own Sales	796.3	3463.2	0	17000	19111.5
To-Date Licensing Revenues	12.5	61.2	0	300	300
To-Date Sales Subtotal	808.8	3524.3	0	17300	19411.5
Expected Own Sales	649	2090.2	0	10000	15575
Expected Licensing Revenues	45.2	162.1	0	750	1085
Expected Sales Subtotal	694.2	2143.8	0	10300	16660
Total Sales	1503	5633.4	0	27600	36071.5

[43] Tables 35 and 36 draw on the data provided in questions survey 6, 10, 12, and 13. Questions 12 and 13 provide information on to-date and expected sales and licensing fees. Question 10 provides information on the value of intellectual property. Question 6 provides information on the additional funding. Chapter 7 provides additional information regarding these questions.

Category	Mean	Std. Dev.	Min	Max	Total
		Intellectual Property Values (n=24)			
Patent Value	0	0	0	0	0
Patent Pending Value	3333.3	11196.5	0	50000	80000
Copyright Value	21.0	102.0	0	500	505
Copyright Pending Value	0	0	0	0	0
Total IP Value	3354.4	11200.2	0	50000	80505
		Total Sales and Intellectual Property Values (n=24)			
Total Sales + IP Value	4857.4	12697.2	0	50300	116576.5
		Project Costs* (n = 27)			
Grant Funding	77.1	22.8	19.71	109.5	2080.6
Additional Investment	615.6	1685.8	0	7117.9	16621.9
Total Investment	692.7	1685.6	54.8	7205.5	18702.5

* Revenues are in $2012 as reported on the Board's survey. Costs were adjusted to $2012 by a chained Gross Domestic Product deflator (U.S. Bureau of Economic Analysis, 2014).

The monetary values in Table 35 indicate sales and licensing fees to date of $19.4 million. Participant firms that responded to the survey (n=24) also expect to receive an additional $16.7 million in own sales and licensing fees. The combined total of to-date and expected sales and licensing fees is $36.1 million. Participating firms also expect the intellectual property (IP) resulting from projects supported by the Fund to have an expected lifetime value of $80.5 million. The total value of to-date and expected sales, licensing fees, and intellectual property is over $116.6 million.

Table 35 also shows the fixed costs of projects supported by the Fund (n=27), by categories: the value of the grant funding and additional investment funding. These costs were assumed to have been incurred in the initial project year and have been adjusted to $2012 using a chained Gross Domestic Product (GDP) deflator. The total amount of inflation-adjusted grant funding is $2.1 million dollars. Additional investment by Fund participants' totals over $16.6 million. The combined total of investment in projects supported by the Fund was $18.7 million.[44]

Table 35 indicates that Fund-supported projects have generated revenues, from all sources, that are greater than their total investment: $116.6 million compared to $18.7 million. This however is a naïve comparison of revenues and costs that does not consider consumer surplus and can be refined further. Toward that end, an economic model that derives the conditions under which the benefit-to-cost ratio is greater than one, outlined in section 8.3, is applied to these data to provide further understanding of the potential net social benefits attributable (discussed below) to the Fund.

Application of the Model

With reference to the data in hand from the Board's survey (Table 35), calculation of total social benefits using equation (8) requires data on revenues and fixed costs of funded projects. The revenue and cost specifications used in the analyses are defined as six cases, where each case includes a different combination of revenues and costs. Table 36 presents the values of costs and revenues used in each case. Cases 1 through 3 assume that fixed costs are only the value of grant funding provided by the state of North Carolina. Each of the three cases in this group, cases 1 through 3, includes progressively

[44] One objective of the Fund was to incentivize the additional investment into the targeted industries in North Carolina. 7 of 24 respondents reported receiving additional funding from a public source. 13 of 24 respondents reported receiving additional funding from a private source. 4 of these firms received funding from both sources. Thus, 13 of 24 firms received additional funding from either public or private sources. Additionally, 13 of 24 respondent firms agreed with the statement that the Fund helped their project obtain additional funding. These figure suggest that the Fund achieved its objective of incentivizing investment, including those from the private sector, to North Carolina's green industry sector. Further, this evidence suggests that firms were able to leverage participation in the Fund to obtain additional external investment.

more categories of revenues starting with only to-date sales and concluding with the inclusion of expected sales and the expected lifetime value of intellectual property. Cases 4 through 6 follow the same progression of revenues as cases 1 through 3 (e.g., case 1 and 4 include the same categories of revenues), but include additional investment costs by Fund participants.

The values of ε^* for each case are calculated by setting fixed costs equal to the total surplus, as calculated from either equation (5) or (8). If the true value of ε is below this calculated value, then the true value of *B/C* is greater than 1. The value of ε^* that solves this equality can be calculated using iterative values of ε. Table 37 presents the results of these calculations. Column (1) in Table 37 identifies the case considered for each row. Column (2) reports the calculated values of ε^*, assuming that there is not a substitute technology. Thus, assuming no substitute technology and case 1, if the elasticity of demand for the technologies that resulted from the grant is 19.18, then *B/C* = 1. Therefore, it may not be unreasonable to conclude from this calculated value of ε^* of 19.18 that *B/C* exceeds 1, implying that the projects supported by the Fund resulted in a positive net social surplus.

Table 36. Revenues and Costs Cases (Reported in $1000s)

Case	Revenues (n=24)	Costs* (n=27)
1	To-Date Sales 19411.5	Grant** 2080.6
2	To-Date + Expected Sales 36071.5	Grant 2080.6
3	To-Date Sales + Expected Sales + IP Value 116576.5	Grant 2080.6
4	To-Date Sales 19411.5	Grant + Additional Investment 18702.5
5	To-Date + Expected Sales 36071.5	Grant + Additional Investment 18702.5
6	To-Date Sales + Expected Sales + IP Value 116576.5	Grant + Additional Investment 18702.5

Note: Sales refers to sales and licensing revenues.
* Revenues are in $2012 as reported on the Board's survey. Costs were adjusted to $2012 by a chained Gross Domestic Product deflator (U.S. Bureau of Economic Analysis, 2014).
** Grant values include investment in non-respondent firms.

The findings presented in Table 37 suggest first that the calculated values of ε are sensitive to the categories of sales and costs included in the analyses, and second the findings suggest that the Fund likely resulted in a *B/C* greater than one. This interpretation of the calculated elasticities assumes that all social economic benefits were attributable to the R&D award from the Fund. With any evaluation, attribution is difficult to quantify. The relevant Board survey question for reporting sales and other revenues was (North Carolina Board of Science and Technology, 2012):

> For your organization and/or your licensee(s), what is the approximate dollar amount of total sales resulting from the technology developed during this project? If multiple grants (from other sources) contributed to the ultimate commercial outcome, report, to the extent possible, *only the share of total sales appropriate to the project supported by this NC Green Business Fund Grant* [emphasis added].

And, the assumption about complete attribution follows from the emphasized phrase above.

Table 37. Calculated Elasticities that Yield *B/C* = 1

(1) Case	(2) No substitute technology	(3) m=1.5	(4) m=1.1	(5) m=1.05	(6) m=1.01
1	19.18 [1.42, 52.20]	19.17 [1.01, 52.20]	17.11 [1.01, 52.00]	14.07 [1.01, 49.79]	10.24 [1.01, 33.15]
2	35.19 [4.48, 86.55]	35.19 [3.75, 86.55]	34.46 [2.37, 86.54]	31.14 [2.15, 85.86]	20.57 [1.99, 61.20]
3	112.56 [29.65, 226.81]	112.56 [29.65, 226.81]	112.56 [28.58, 226.81]	112.33 [25.06, 226.81]	89.13 [16.83, 213.06]
4	2.70 [1.05, 8.01]	1.65 [1.01, 7.75]	1.16 [1.01, 5.28]	1.10 [1.01, 4.49]	1.05 [1.01, 3.88]
5	4.43 [1.38, 13.39]	3.69 [1.01, 13.35]	2.34 [1.01, 10.73]	2.13 [1.01, 8.72]	1.97 [1.01, 6.86]
6	12.99 [3.16, 39.73]	12.94 [2.19, 39.73]	10.29 [1.46, 39.21]	8.38 [1.37, 36.16]	6.64 [1.30, 23.76]

Note: Bootstrapped 90% confidence intervals presented in brackets. Values were calculated using 1000 repetitions.

The other values of ε^* in column (2) show that as the categories of sales included in the benefit calculations increase, the values of ε^* also increase in absolute value. Similarly, as the categories of costs included in the cost calculations increase, the values of ε^* decrease in absolute value when compared to the corresponding measure of benefits (e.g., case 1 compared to case 4). Perhaps the most inclusive representation of benefits and costs is that for which benefits include all current and expected future sales and for which costs include grant funding and additional investments; this is case 6. In this case, the values of ε^* is 12.99.

Columns (3) through (6) show that values of ε^* decreases in absolute value as the relative price of a substitute technology decreases (i.e., *m* decreases). These values ε^* are calculated by including only the change in net surplus, which is determined in part by the relative price of the existing technology, *m*. If one knew the true values of *m* for a given technology, then one could include it as a refinement of the model. Here, the true value of *m* is unknown. Instead, values of *m* for these calculations are arbitrarily chosen for illustration purposes to represent a substitute whose price was 1.5, 1.1, 1.05, and 1.01 times greater than that of the developed technology. These values, or other similar values, demonstrate the responsiveness of the values of ε^* to changes in the relative price. The values of ε^* for $m = 1.5$, for example, differ by more than .10 from those where no existing technology is present in only cases 4 and 5, which are the most conservative cases in terms of included costs and benefits.

One limitation of the application of this evaluation model is an inability to conduct hypothesis testing. That is to say, the model provides a calculated value of ε^*, but it says nothing about the variation of this value. Here, a bootstrapping routine is applied to provide an estimate of confidence intervals around the calculated values of ε^*. This procedure uses the methodology outlined in Greene (2008) to provide a set of bootstrapped values of ε^*. A value of ε^* is calculated using a random sample of 27 observations that are drawn, with replacement, from the population of firms. This process is repeated 1000 times to generate a distribution of ε^* values. This distribution is used to determine a new critical t-value for hypothesis testing. However, as there is no initial estimate of the standard error associated with ε^*, it is impossible to use the hypothesis testing outlined in Greene. Instead, the bootstrapped confidence intervals are presented in an effort to provide some insight into variability of ε^*. Bootstrapped 90 percent confidence intervals are presented below each value of ε^* in Table 37. These intervals are included to provide some semblance of the variation of these calculated values. Caution is urged in the interpretation of these estimates. To that end, no claims of statistical significance of these ε^* values are suggested.

Figure 10. Changes in *B/C* Relative to Changes in ε

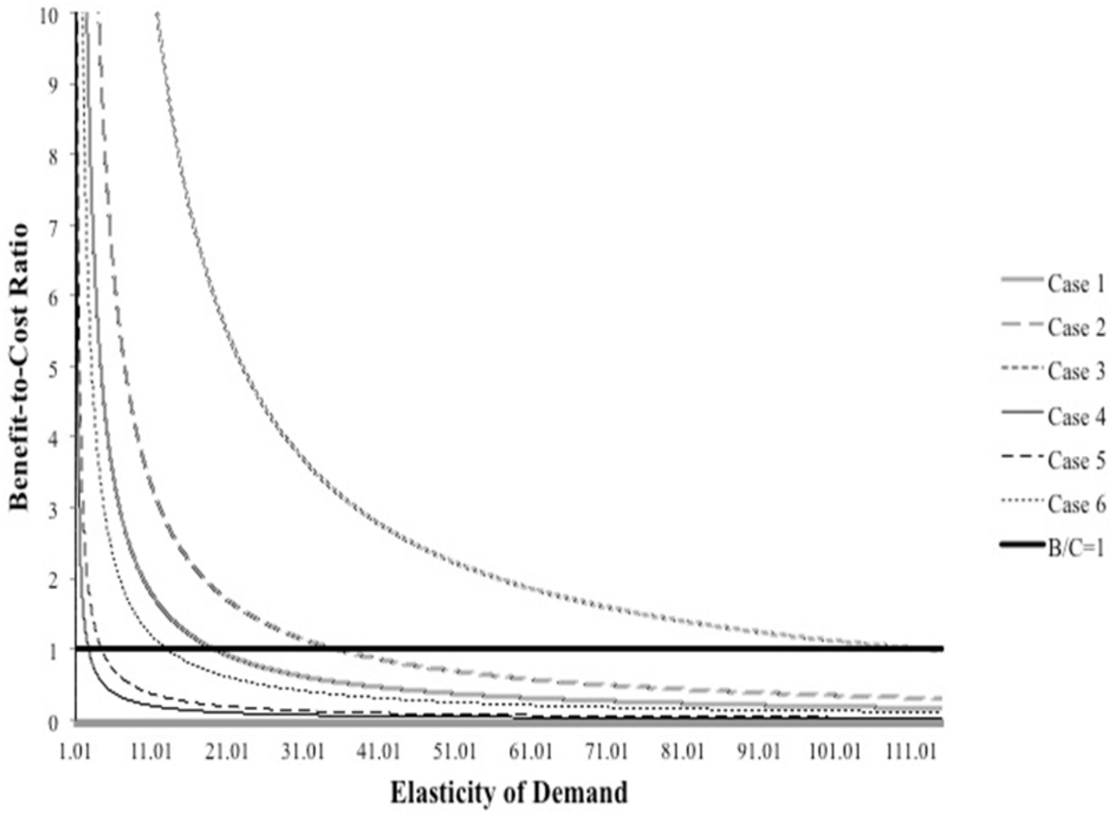


Figure 10 illustrates the relationship between ε and *B/C*. The horizontal axis depicts the elasticity of demand. The vertical axis depicts the benefit-to-cost ratio. A horizontal line at *B/C* = 1 is drawn to demonstrate that the value of ε^* is the horizontal distance at which a given curve crosses that line. Thus, for a given case, ε^* is determined by the intersection of the respective case curve and the *B/C* = 1 horizontal line. Further, Figure 10 indicates that if the true value of ε is less than ε^* then the *B/C* is greater than 1.

The calculated values of ε^* presented in Table 37 can be compared to other estimated elasticities of demand to provide a sense of their magnitude and the prospect that the Fund resulted in a *B/C* greater than one. Beresteanu and Li (2011) examine demand for hybrid vehicles in the United States. The market for hybrid vehicles is competitive (the model above assumed the funded firm has a market advantage), which leads to a larger and therefore less favorably comparable elasticity of demand to that calculated for the Fund. These authors provide estimations of the own-price elasticity of demand that range in absolute value from 7.61 to 10.87, with an average of 8.86. If the elasticity of demand for the technologies developed as part of the Fund were 8.86, the benefit-to-cost ratio for case 1 would be 2.24 using equation (5). That is to say, under those conditions, the Fund resulted in benefits that were 2.24 times as large as the fixed costs and therefore net social surplus was positive. If one assumes an existing technology is present and has a price that is 1.01 times the price of the developed technology, the *B/C* for case 1 at an elasticity of 8.86 is 2.14 using equation (8). *B/C* values of 2.24 and 2.14 calculated using an elasticity of demand from a highly competitive market provide suggestive evidence that the Fund resulted in a positive net social surplus.

Findings

This chapter examined the economic impacts of North Carolina's Green Business Fund, a state-level sustainability-technology program. The Fund is not unique in its objectives or mechanisms, as more than 20 percent of all states have implemented a broadly similar program. To the extent that the Fund is comparable to those programs, the results from this evaluation might be used to guide policy makers in those states and in states that may consider implementing such a program.

The Fund was evaluated using a novel model that can be employed when researchers are unable to decompose revenues into prices and quantities. This data problem restricts one from using models that would otherwise provide a more direct valuation of the surplus generated by a program.

The results from this evaluation suggest that the Fund has indeed generated positive net social benefits, and therefore achieved its legislative objective of growing the green industry sector in North Carolina. When compared to the elasticity of demand for hybrid vehicles, the model suggests that the Fund resulted in a benefit-to-cost ratio of 2.24 when no existing technology was present and 2.14 when an existing technology has a price 1.01 times that of the newly developed technology.

Any generalizations from this analysis should be made with caution and with qualification. First, this evaluation only considers benefits derived from current and expected future sales of the technologies and includes no estimate of environmental or health benefits. Inclusion of non-pecuniary benefits would lead to even higher *B/C* values. Because the technologies developed using Fund monies were of a sustainability nature, it is reasonable to assume that some positive environmental benefits should be included in the analysis. Unfortunately, data limitations prevent the inclusion of such non-pecuniary benefits into this analysis. However, inclusion of these benefits would result in an increase of the calculated elasticity of demand for which $B/C = 1$.

Second, the findings presented herein are for one small state program; generalizations to other state programs should only be made with caution. Although the state-level sustainability-technology programs discussed in Chapter 5 were restricted to those employing the same mechanisms (i.e., direct subsidization) and the same target markets (i.e., the nexus between sustainability and innovation) there are differences among programs. One major difference is the value of the grant monies provided by the Fund. The combined budget of the Fund for the two years under consideration was $2 million. Larger programs that cover a broader range of firms and projects may yield different results than the Fund.

The research presented here has outlined only a portion of the landscape of evaluating publicly-funded sustainability-technology programs. Avenues for future research include extending the model to include additional categories of benefits such as pollution reduction and non-renewable resource saving, relaxing the assumptions about the nature of the market for newly developed technologies, and applying such models to other programs to expand the set of results that researchers and policy makers might use for comparisons.

CHAPTER IX

ANALYSES OF EMPLOYMENT, INTELLECTUAL PROPERTY, AND REVENUES

This chapter presents the results from econometric analyses of the Fund along the outcome dimensions of job growth, intellectual property creation, and revenues.[45] These outcomes were chosen because of their close link to the impetus for the Fund and to the economic growth (i.e., surplus gains) associated with the funded projects. Subsequently, understanding relationships between firm- and project-characteristics and these outcome dimensions can inform future policy choices.

The analyses herein examine the relationship between project characteristics and project outcomes and outputs. A model is estimated that follows the general form:

(1) $Y_i = f(\mathbf{X},\mathbf{Z})$

Y_i represents one of three variables: the number of FTE jobs created, whether an IP was created, or the value of revenues associated. These variables are based on the outcomes or outputs attributable to the funded project. **X** and **Z** are firm- and project-specific vectors, respectively. The function *f* defines the relationship between the dependent and independent variables and will be specified based on theoretical and practical considerations.

[45] This chapter draws directly from Hall and Link (2015).

The remainder of this chapter is organized as follows. Section 9.1 presents an overview of the data used in these analyses. Sections 9.2, 9.3, and 9.4 examine the results of estimating equation (1) using the output dimensions listed above as Y_i. Section 9.5 summarizes the results and present potential interpretations.

Overview of Data

The data used in these analyses are drawn from the survey described in Chapter 7. Table 38 defines the particular variables used in these analyses.

Table 38. Definitions of Variables

Variable	Definition
Employ	Number of new full-time equivalent employees in the funded organization that are directly attributable to the project supported by the Fund as of 2012
IP	An indicator that takes the value of 1 when a project resulted in the creation of intellectual property (i.e., patent or copyright) and 0 otherwise.
Revenues	The reported sum of all revenues and licensing fess that are directly attributable to projects supported by the Fund in $1000000
Grant	Dollar amount of the Fund award in $1000
Disc	A binary variable equal to 1 if the funded project was discontinued as of 2012, and 0 otherwise
Comm	A binary variable equal to 1 if the technology from the Fund project has been commercialized as of 2012, and 0 otherwise
AddInvest	Dollar amount of additional funding that the organization received during its conduct of the Fund funded project in $1000
Univ	A binary variable equal to 1 if a university was involved in any way with the project, and 0 otherwise
AddInvest/Grant	Ratio of additional investment dollars to Fund grant dollars

The first three variables defined in Table 38 are the outcomes of interest for the econometric analyses herein: the number of new FTE employees in the funded organization (*Employ*), an indicator for the creation of intellectual property (*IP*), and the sum of revenues and licensing fees that are attributable to the fund (*Revenues*).

The value of monies awarded via the Fund (*Grant*) is the first independent variable defined in Table 38. This variable is important for consideration because these monies are inputs into the innovation process and policy makers can exercise control over its value.

The next two variables indicate the status of the projects at the time of the survey: an indicator for the discontinuation of the project (*Disc*), and an indicator for the commercialization of the resultant technology (*Comm*). As Disc and Comm are mutually exclusive but not mutually exhaustive, there is a group of projects for which Disc = 0 and Comm = 0; these projects are still underway but have not been successfully commercialized. Inclusion of these variables is based on the idea that projects that have been discontinued (i.e., *Disc = 1*) are hypothesized to have created fewer jobs, to be less likely to have resulted in a patent or copyright, and to have resulted in lower revenues than projects that have not been discontinued. Likewise, projects that have been successfully commercialized are more likely to have created more jobs, to be more likely to have resulted in a patent or copyright, and to have resulted in more revenues than projects that have not been successfully commercialized.

Two variables control for resources available for the project in addition the monies provided by the grant. A variable denoting the additional monies from other sources (*AddInvest*) provides information on the availability of inputs into the innovation process for each project. An indicator for a partnership with a university (*Univ*) provides a measure of external knowledge available as an input into the innovation process. The rationale for inclusion of these variables into the analyses is that firms with greater resources may have produced higher levels of the outputs of interest.

The variable *AddInvest/Grant* indicates the ratio of additional monies from other sources to monies awarded via the Fund. This variable is included as an alternative to the variables *Grant* and *AddInvest* and provides information on how the relative source of financial resources impacts outcomes of interest.

Beyond the variables defined here, the econometric analyses include the logs of some variables (e.g., *lnGrant*) andinteraction terms (e.g., *Univ*Comm*). The logarithm of one variable, *AddInvest,* merits particular attention. For some firms, the value of *AddInvest* is zero, and thus the *lnAddInvest* is undefined. To account for this, the values of *lnAddInvest* that are undefined are replaced with 0. Additionally, the specifications for which *lnAddInvest* is included also include an indicator variable, *Control*. *Control* takes a value of 1 when *lnAddInvest* has been changed to 0, but is 0 otherwise.

These analyses also include interaction terms to examine how the impacts of variables change when the conditions of the project change. For example, one may ask if commercialization has a different impact on an outcome of interest when a firm has partnered with a university as opposed to not having commercialized.

Table 39. Descriptive Statistics of the Variables, n=24

	Mean	Std. Dev.	Min	Max
Employ	2.46	4.04	0	16
IP	0.21	.41	0	1
Revenues	1.50	5.63	0	27.6
Grant ($1000)	68.75	21.12	18	100
Disc	0.21	0.41	0	1
Comm	0.21	0.41	0	1
AddInvest ($1000)	632.46	1622.53	0	6500
Univ	0.5	0.51	0	1
AddInvest/Grant	9.61	23.23	0	83.33

Table 40. Correlation Matrix of the Variables

	Employ	*IP*	*Revenues*	*Grant*	*Disc*	*Comm*	*AddInvest*	*Univ*	*AddInvest/ Grant*
Employ	1.000								
IP	-0.008	1.000							
Revenues	0.211	0.401	1.000						
Grant	-0.259	-0.425*	0.020	1.000					
Disc	-0.293	-0.263	-0.140	0.310	1.000				
Comm	0.485*	-0.011	-0.025	-0.266	-0.263	1.000			
AddInvest	0.437*	-0.051	0.180	0.014	-0.178	0.138	1.000		
Univ	-0.221	-0.103	0.1521	0.396	0.103	-0.103	-0.285	1.000	
AddInvest /Grant	0.513*	-0.003	0.179	-0.061	-0.198	0.186	0.983*	-0.320	1.000

* 0.05 level or better of significance

Tables 39 and 40 summarize the variables used in these analyses. Table 39 presents descriptive statistics of the variables. Table 40 presents a correlation matrix of the variables.

The issue of attribution or causality needs to be addressed when conducting econometric analyses. Here, attribution of these outcomes to the Fund is derived from the precise language in the survey instrument. That is, the survey instrument asks for only the outputs or outcomes that can be attributed directly to the funded project. Chapter 7 discusses attribution in greater detail.

Analysis of Job Growth

The first outcome of interest is the numbers of jobs created that are attributable to the Fund. Here, Y_i in equation (1) is takes on the value of the FTE jobs created at a particular firm.

Table 41 provides a descriptive analysis of the employment growth attributable to the Fund and that growth's relationship to the level of award provided by the Fund. The average employment growth among all organization in the sample was 2.46 FTE jobs with a minimum of 0 and a maximum of 16. When the sample is restricted to private organization the average employment growth is 2.71 FTE jobs with a minimum of 0 and a maximum of 16. Restricting the sample to public organization results in an average employment growth of 0.67 FTE jobs with a minimum of 0 and a maximum of 2.

Table 41. Descriptive Table on Employment and Grant

	All Organizations (n = 24)				Private Organizations (n=21)				Public Organizations (n=3)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Employ	2.46	4.04	16	16	2.71	4.26	0	16	0.67	1.15	0	2
Employ /Award	0.05	0.09	0.33	0.33	0.06	0.10	0	0.33	0.007	0.01	0	0.02

Note: Employ/Award is calculated as FTE job created per $1000 of award.

Hall and Link (2015) describe the relationship expressed in table 10.4 between employment growth and awarded monies as follows:

> On one hand, one can approximate from an aggregate average that there were about 30 new jobs per $1,000,000 of grant funding attributable to the NC Fund: 59 new jobs per $2,000,000. On the other hand, one can approximate from an average of averages that there were about 50 new

> jobs per $1,000,000 of award funding attributable to the Fund: 0.05 new jobs per $1000 from Table 1. Regardless, this range of approximate dollar per new job is in line with Link and Scott (2012) estimate that the Small Business Research (SBIR) programs in the US Department of Defense, the National Institutes of Health, NASA, and the US Department of Energy can be created with an average of about 42 new jobs per $1,000,000 of award funding.

Additional analysis of the employment growth attributable to the fund was conducted via the application of a Tobit model that defines the number of created jobs attributable to the Fund as the dependent variable. Table 42 presents the results of this analysis. Column (1) presents the results from a model that considers the variables *Grant*, *Disc*, *Comm*, and *AddInvest*, and two interaction terms *Univ*Disc and Univ*Comm* as the dependent variables. Column (2) presents results from a model that follow's Column (1) but replaces the *Grant* and *AddInvest* terms with the log of each. Further, an indicator *Control* is included that takes the value 1 when *AddInvest* is 1. Similarly, Column (3) of replaces *Grant* and *AddInvest* terms with the term *AddInvest/Grant*, which is the ratio of additional investment and the value of the grant.

One may observe several notable relationships by examining Table 42. First, these results do not suggest a statistical relationship between the size of the grant and the number of jobs created. Second, the findings do suggest a relationship between the amount of additional funds received by the firm and the number of jobs created. Third, and finally, the results suggest that universities play a mitigating role in job creation: decreasing the number of jobs lost when a project ends prematurely and decreasing the number of jobs created when the project is successfully commercialized.

Table 42. Regression Estimates, *Employ* (standard errors)

Variable	(1)	(2)	(3)
Grant	-0.023	--	--
	(0.038)		
lnGrant	--	-1.58	--
		(1.93)	
Disc	-20.64	-18.40	-19.95
	(4.52)***	(3.81)***	(4.43)***
Comm	6.74	6.11	6.67
	(4.25)	(4.12)	(4.17)
AddInvest	0.0009	--	--
	(0.0006)		
lnAddInvest	--	1.09	--
		(0.73)	
Univ	1.08	0.67	1.03
	(1.56)	(1.37)	(1.73)
*Univ*Disc*	17.67	15.48	19.95
	(4.96)***	(4.09)***	(4.48)***
*Univ*Comm*	-6.62	-4.93	-6.43
	(4.67)	(4.69)	(4.59)
Control	--	10.85	--
		(8.74)	
AddInvest/Grant	--	--	0.069
			(0.045)
Intercept	1.80	5.87	0.21
	(2.98)	(22.5)	(1.32)
Pseudo R^2	.1456	.1678	.1520
Tobin's sigma	3.51	3.33	3.44
	(0.86)***	(0.82)***	(0.82)***
χ^2 (df)	16.21(7)	18.69(8)	16.92(6)
Log likelihood	-47.56	-46.32	-47.21

Note: The intercept term captures those projects that are either still underway or that for which commercialization is underway but not completed.
The regression results are from the estimation of a Tobit model due to the truncation of the dependent variable, *Employ*, at 0. See Table 10.2.
*** 0.01 level of significance; ** 0.05 level of significance; * 0.10 level of significance
Log likelihood tolerance was adjusted to .0000000005 in STATA, standard errors were calculated as robust, and marginal effect standard errors were calculated using the delta method.

Analysis of Intellectual Property Creation

The second outcome of interest is the creation of intellectual property. Table 43 describes the frequency of IP generation that was directly related to the Fund. 5 organizations, 20.83 percent, generated at least one patent or copyright. 19 organizations, 79.17 percent, reported no IP creation.

Table 43. Descriptive Table on IP

	Frequency	Percentage
No IP Created	19	79.17
IP Created	5	20.83

The creation of intellectual property (*IP*) is further analyzed in a manner similar to the one employed to examine job creation. However, in lieu of a tobit model, the binary nature of the *IP* variable suggests the use of a probit model. Table 44 presents the estimated marginal effects derived from a probit model that takes *IP* as the dependent variable and firm and project characteristics as the dependent variables.

Column (1) presents a model that controls for the size of the grant, whether the product has been successfully commercialized, the amount of additional investment, whether the firm had a university partner, and the interaction of the university partner and successful commercialization variables. The discontinued project variable and the interaction of that variable with university has been omitted as they were perfectly predicted the outcome. Subsequently, the base group for analyses changes from ongoing projects to all projects that have not successfully commercialized.

Table 44. Regression Estimates, *IP* (standard errors)

Variable	(1)	(2)	(3)
Grant	-0.00765***	--	--
	(0.00235)		
Comm	-0.279***	-0.268***	-0.253***
	(0.0813)	(0.0657)	(0.0972)
AddInvest	0.0000143	--	--
	(0.0000372)		
Univ	-0.0604	-0.0110	-0.197
	(0.177)	(0.114)	(0.169)
*Univ*Comm*	0.767***	0.773***	0.770***
	(0.0770)	(0.0594)	(0.0929)
lnGrant	--	-0.426***	--
		(0.125)	
lnInvest	--	0.0798***	--
		(0.0391)	
Control	--	0.623***	--
		(0.0466)	
AddInvest/Grant	--	--	0.000988
			(0.00394)
Pseudo R^2	0.345	0.535	0.158
Wald χ^2 (df)	233.38(5)	285.14(6)	178.75(4)
Log likelihood	-8.04	-5.71	-10.34

Note: The intercept term captures those projects that have not been successfully commercialized.
The marginal effects are calculated as the average marginal affect, but the marginal affects at population means were similar in direction and relative significance. These marginal effects derived from the regression estimations obtained from a Probit model due to the binary nature of the dependent variable, *IP*. See Table 10.2.
*** 0.01 level of significance; ** 0.05 level of significance; * 0.10 level of significance
Standard errors were calculated as robust, and marginal effect standard errors were calculated using the delta method.

The results from column (1) suggest that commercialization by itself did not have a positive statistical impact on the generation of IP. In fact, the marginal effect of the *Comm* is negative and statistically significant. The estimated marginal effect for *Univ* is likewise negative but is not statistically significant. However, when the interaction of *Comm* and *Univ* are taken into account the net effect of having both successfully commercialized and having a university partner results in a positive and statistically significant effect on the likelihood of a project resulting in the creation of IP.

Columns (2) and (3) test the robustness of estimated marginal effects to changes in model specification. Column (2) replaces the *Grant* and *AddInvest* variables in column (1) with the logs of each, respectively *lnGrant* and *lnInvest*, and adds the indicator variable *Control*. For observations whose value of *AddInvest* is 0, the value of *lnInvest* is set as 0. The *Control* variable takes the value of 1 when *AddInvest* is 0 and when *AddInvest* is greater than 0. Column (3) replaces the *Grant* and *AddInvest* variables in column (1) with the ratio of these two terms *AddInvest/Grant*.

The estimated marginal effects for *Comm*, *Univ*, and *Univ*Comm* are very similar across all three models. The same general directions and magnitudes persist. This suggests that the estimated marginal effects are robust to the changes presented here. That is the estimates marginal effects are as follows, *Comm* is negative and statistically significant, *Univ* is positive but not statistically significant, and their interaction *Univ*Comm* is positive and statistically significant.

These results suggest that successful commercialization itself is not enough to lead to the creation of IP, but when firms have a university partner with them they are more likely to create new IP. One way of interpreting this suggestion is that universities are involved in projects that are more likely to lead to new technologies that are sufficiently novel to warrant protection. An alternative interpretation is that university partners require an arrangement that clearly defines property rights and are more likely to seek patents for administrative reasons.

From a policy perspective, the first interpretation suggests that funding should be allocated more heavily towards projects that demonstrate an ability to partner with universities (i.e., result in more novel technologies). The second interpretation provides less advice as it may be unclear as to whether the IP generation is beneficial as it stems from administrative requirements instead of the production of higher-quality technologies.

Analysis of Revenues

The third, and final, outcome of interest in is the value of revenues generated by funded projects. These revenues include both to-date and expected sales and licensing revenues and are denoted as the variable *Revenues*.

Table 45 provides descriptive analysis of revenue generation. The average revenue generation for the sample of all firms was 1.50 million dollars with a minimum of 0 and a maximum of 27.6 million dollars. When the sample is restricted to private organizations the average revenue generation was 1.71 million dollars with a minimum of 0 and a maximum of 27.6 million. Among public organizations the average revenue generation was 0.026 million dollars with a minimum of 0 and a maximum of 0.078 million.

Table 45. Descriptive Table of *Revenues*

	All Organizations (n = 24)			Private Organizations (n=21)			Public Organizations (n=3)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Revenues ($Millions)	1.50	5.63	0-27.6	1.71	6.01	0-27.6	0.026	0.045	0-.078
Revenues /Award	23.20	75.89	0-368	26.47	80.82	0-368	0.27	.47	0-.82

Note: Revenues/Award are calculated as dollar of revenue per dollar of award.

Analyses of revenues per award dollar can be conducted in a manner similar to that employed to analyze employment growth per award dollar. One may compare the aggregate revenues of 36.07 million dollars to the total award of 2 million dollars to obtain 18.04 million dollars in revenues per 1 million dollars in award funds. Alternatively, one may employ an average of averages calculation to derive a valuation of 23.2 million dollars in revenues per 1 million dollars in awarded funds.

Table 46. Regression Estimates, *Revenues* (standard errors)

Variable	(1)	(2)	(3)
Grant	-0.143*	--	--
	(0.0875)		
lnGrant	--	-13.74**	--
		(7.524)	
Disc	-39.46***	-10.48	-40.32***
	(15.41)	(8.397)	(15.97)
Comm	5.609**	8.180*	5.587*
	(3.028)	(5.331)	(3.453)
AddInvest	0.00227**	--	--
	(0.00126)		
lnAddInvest	--	4.899**	--
		(2.626)	
Univ	10.34	18.41*	7.314
	(8.164)	(11.13)	(7.069)
*Univ*Disc*	-5.384	-25.74*	-7.480
	(6.538)	(15.01)	(7.314)
*Univ*Comm*	-5.935	-1.817	-5.318
	(6.026)	(4.770)	(5.647)
Control	--	43.68*	--
		(25.10)	
AddInvest/Grant	--	--	0.127*
			(0.0762)
Intercept	-0.230	79.39*	-7.421*
	(3.833)	(47.19)	(4.821)
Pseudo R^2	0.107	0.211	0.095
Tobin's sigma	7.949***	6.037***	7.984***
	(3.352)	(1.695)	(3.370)
χ^2 (df)	2.35(7)	2.73(8)	2.25(6)
Log pseudolikelihood	-42.01	-37.15	-42.60

Note: The intercept term captures those projects that are either still underway or that for which commercialization is underway but not completed.
The regression results are from the estimation of a Tobit model due to the truncation of the dependent variable, *Revenues*, at 0. See Table 10.2.
*** 0.01 level of significance; ** 0.05 level of significance; * 0.10 level of significance
Log likelihood tolerance was adjusted to .0000000005 in STATA, standard errors were calculated as robust, and marginal effect standard errors were calculated using the delta method.

Table 46 presents the regression estimations where generated revenues are the dependent variable. The specifications for these analyses follow those presented in the analyses of job creation.

The results presented in Table 46 suggest that the status of a project is statistically significantly related to the revenues generated by that project. Discontinued projects are negatively associated with revenues at a statistically significant level. Commercialized projects are positively associated with revenues at a statistically significant level. These results are trivial but conform to the definitions of commercialization and discontinuation of projects.

The results presented in Table 46 also suggest that projects with additional investment are positively and statistically significantly associated with higher levels of revenues. Interpretation is difficult as the direction of causality is unclear. That is, projects that are be more likely to be successful have an easier time attracting funding or projects that attract funding are more likely to be successful because they have more resources to draw from. Both cases could be true, presenting the potential for a positive feedback loop.

Policy suggestions derived from these results focus on the ability of projects to obtain additional funds. Notably, the positive relationship between additional funding and revenues suggests that policy makers wishing to enhance the success of a program similar to the Fund could do so by favoring projects that have demonstrated the ability to attract investment from other sources. This suggestion is not without the caveat that doing so might only serve to reinforce a positive feedback loop that which results in otherwise successful projects missing out on funding and thus failing.

Summary

This chapter presented the results from econometric analyses of the Fund along the outcome dimensions of job growth, intellectual property creation, and revenues. These outcomes were chosen because of their close link to the impetus for the Fund and to the economic growth (i.e., surplus gains) associated with the funded projects.

An over-arching result is that the success or failure of a project is significantly related to its ability to generate outcomes of interest: FTE jobs created, IP created, and revenues generated. This is expected given the definition of project success (i.e., commercialization) and failure (i.e., discontinuation). However, the relationships between these factors and other project characteristics have some impact on these outcomes as well. Further, the estimates suggest that some project characteristics are significantly related to the outcomes of interest even when success and failure are accounted for.

Analysis of the number of jobs created suggests that a university partner has the ability to attenuate the impact of project success or failure on the number of jobs created.

Estimations regarding the relationship between project characteristics and the creation of IP suggest that university partnerships are positively associated with IP generation.

Revenues estimations suggest that ability to draw additional funding is positively related to revenue generation. One must be careful when interpreting this result, as the direction of causality is unclear. However, if a policy maker wished to increase the number of successful firms they allocated resources to, they may be able to do so by favoring firms that have demonstrated the ability to obtain external funding.

CHAPTER X

CONCLUSIONS AND SUMMARY REMARKS

This work has examined North Carolina's Green Business Fund. One may draw several conclusions from the empirical analyses presented in Chapters 5, 8, and 9. This chapter provides a brief summary of these conclusions.

First, the analysis of the spread and adoption of sustainability technology (ST) programs in other states presented in Chapter 5 suggests that these programs have become increasingly more prevalent across states over time. Currently, 12 states had adopted an ST program. One may interpolate the observed trend and extend it into the future to conclude that these more states are likely to adopt ST programs in the future. Chapter 5 presented several suggestions as to why some states might adopt ST programs earlier than others. These suggestions included: a culture of awareness present in some states and R&D-intensive firms and industries are able to influence the policy makers in their states.

Second, Chapter 8 presents an evaluation of the Fund. This evaluation draws on the traditional evaluation literature and provides insight as to the benefit-to-cost ratio of the Fund. The model presented in Chapter 8 allows one to estimate the relationship between the elasticity of demand for the technologies developed by the Fund and the benefit-to-cost ratio of the program itself. With an understanding of this relationship in hand, the chapter then determines the elasticity of demand required for the Fund to result in a B/C that is equal to 1. These calculated elasticities of demand were sufficiently high as to suggest that the Fund likely resulted in a benefit-to-cost ratio that was greater than 1.

As an extension, Chapter 8 presents the calculated B/C ratio for the Fund when the elasticity of demand is assumed. In particular, the elasticity of demand was assumed to match that for hybrid vehicles in the United States. This demand elasticity was relatively high in absolute value (i.e., 8.86) suggesting that the market for hybrid vehicles is very competitive. When the market for technologies developed by Fund participants was assumed to be similar, the calculated B/C cost ratios were greater than 2. This suggests that the net social surplus from the Fund was indeed positive.

Third, and finally, Chapter 9 employed empirical econometrical modeling to examine the relationships between employment outcomes and firm- and project-characteristics. These outcomes of interest included the number of jobs created, the creation of intellectual property, and the value of generated revenues. Notable firm- and project-characteristics included the status of the project (e.g., discontinued, commercialized), the value of additional investment, the value of the grant award, and whether or not the participant partnered with a university. A primary over-arching result of these analyses is that the discontinuation or successful commercialization of a technology was strongly related to the observed outcomes of interest. Analysis of the number of jobs created suggests that a university partner has the ability to attenuate the impact of project success or failure on the number of jobs created. Estimations regarding the relationship between project characteristics and the creation of IP suggest that university partnerships are positive related to IP generation. Analysis of revenue generation suggests that there is a positive relationship between additional investment from sources other than the Fund and the creation of revenues.

Policy makers who are considering establishing a ST program can draw all of these results upon. The results of the exploratory analysis in Chapter 5 suggest that policy makers will likely be doing just that. Given the results of the evaluation of Fund, one may conclude that a similar ST program can generate positive net social surpluses. Following the analyses presented in Chapter 9, policy makers may tailor their selection criteria to focus on projects that are able to create partnerships with universities and generate additional investments from external sources.

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APPENDIX A

TEXT OF THE SURVEY INSTRUMENT

Survey Instrument – Green Business Fund

Company Info

- **(1)** <u>If</u> your company's manufacturing/work site(s) are different from its R&D site(s), please provide, <u>for the two largest manufacturing/work sites</u> (*designated below as sites A and B)*, the Address, City, County, State, & Zip Code, as well as the current # of employees (broken down by 6 categories). You may use fractions of full-time effort (e.g., 1 full time employee plus 1 half-time employee = 1.5 employees).
    - Physical Address
    - City
    - County
    - State
    - Zip Code
- EMPLOYEES (per mfg./work site, if applicable)
    - Professional/Scientific
        - Obs: 15
        - Mean: 6.75
        - StdDev: 9.3248
    - Management
        - Obs: 15
        - Mean: 2.07
        - StdDev: 1.7512
    - Technical/Technician
        - Obs: 15
        - Mean: 2.87
        - StdDev: 3.1818
    - Skilled Labor
        - Obs: 15
        - Mean: 1.27
        - StdDev: 3.0582
    - Unskilled Labor
        - Obs: 15
        - Mean: .77
        - StdDev: 2.0777

- Other
  - Obs: 15
  - Mean: .61
  - StdDev: 1.1465

- **(2)** What was your company's total gross revenue for its most recent fiscal year? *(Note: If your fiscal year just ended and you do not yet have an accurate accounting for that year, provide information for the fiscal year before the one that just ended).*
  - <$99,000
    - 7
  - $100,000-$499,999
    - 5
  - $500,000-$999,999
    - 3
  - $1,000,000-$2,499,999
    - 5
  - $2,500,000-$4,999,999
    - 2
  - $5,000,000-$7,499,999
    - 1
  - $7,500,000-$9,999,999
  - $10,000,000-$14,999,999
  - $15,000,000-$19,999,999
  - $20,000,000-$29,999,999
    - 1
  - $30,000,000-$39,999,999
  - $40,000,000+
  - Non-Response:
    - 3

- **(3)** Please list the current total # of employees per category for all your company's sites (i.e., R&D, Manufacturing, and Work) combined. You may use fractions of full-time effort (e.g., 1 full time employee plus 1 half-time employee = 1.5 employees). Enter 0 in categories having no employees.
  - Professional/Scientific
    - Obs: 21
    - Mean: 10.333
    - StdDev: 19.043
    - Range: 0 to 65

- Management
  - Obs: 21
  - Mean: 3.857
  - StdDev: 7.4348
  - Range 0 to 35
- Technical/Technician
  - Obs: 21
  - Mean: 2.381
  - StdDev: 2.941
  - Range: 0 to 12
- Skilled Labor
  - Obs: 21
  - Mean: 3.190
  - StdDev: 6.824
  - Range: 0 to 30
- Unskilled Labor
  - Obs: 21
  - Mean: 1.14
  - StdDev: 2.516
  - Range: 0 to 10
- Other
  - Obs: 21
  - Mean: 1.476
  - StdDev: 2.857
  - Range: 0 to 12

Project Status

- **(4)** What is the current status of the project supported by the NC Green Business Fund Grant? *Select the one best answer.*
  - "The project's efforts at this company have been discontinued"
    - 5
  - The Project's R&D or technology development are still underway
    - 7
  - Commercialization of the Project is Underway
    - 7
  - The products/processes/services are in use by target population/customers/consumers
    - 5

- **(5)** Did the reasons for discontinuing this project include any of the following? *Please select all that apply and then designate the one primary reason below.*
    - Technical failure or difficulties
        - 2
    - Market demand too small
        - 1
    - Level of technical risk too high
        - 2
    - Not enough funding
        - 2
    - Company shifted priorities
        - 1
    - Principal investigator left
        - 1
    - Project goal was achieved (e.g. prototype delivered for federal agency use)
        - 0
    - Licensed to another company
        - 0
    - Product, process, or service not competitive
        - 0
    - Other Reasons
        - 1

Funding & Assistance

- **(6)** To date, what has been the approximate total additional research or development funding directly for this project *(Note: Click on the + symbols below to expand the categories. Enter numbers. If none or unkown, enter 0).*
    - Private Sector
    - Public Sector
    - Other

- **(6.2)** Select the most applicable response to the following statement: *The NC Green Business Fund Grant helped my organization receive funding from one or more of the sources above* (Note: If no additional funding has been received, select "4. Neutral"):
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
        - 11
    - Slightly Agree
        - 4
    - Moderately Agree
    - Strongly Agree
        - 9

- **(7)** In executing this project, was there any involvement by, or use of, university/college faculty, graduate/undergraduate students, and/or university/college facilities or equipment?
    - Yes/No
        - 12 Yes

- **(7.2)** If Yes, select the most applicable response to the following statement: *The Green Business Fund Grant enhanced the scope or quality of my company's partnership with a university or college:*
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
        - 1
    - Slightly Agree
    - Moderately Agree
        - 2
    - Strongly Agree
        - 9

- **(7.3)** If the answer to 7.2 was any one of the three 'Agree' choices, was/were any of the university(ies) or college(s) based in North Carolina?
    - Yes/No
        - 12 Yes

- **(7.4)** If Yes, which university(ies) or college(s) *(Note: separate with commas)*:
    - List of Uni's

- **(7.5)** Did this partnership lead to, or will it likely lead to, additional partnerships with the university(ies) or college(s) on other projects?
    - Yes/No
        - 11 Yes

- **(8)** In executing this project, was there any involvement by, or use of, other company/non-profit organization personnel and/or other company/non-profit facilities or equipment?
  *Other Company/Non-Profit Involvement
    - Yes/No
        - 6

- **(8.2)** If Yes, select the most applicable response to the following statement: *The NC Green Business Fund Grant enhanced the scope or quality of my organization's partnership with other company(ies) and/or non-profit(s)*
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
    - Slightly Agree
        - 1
    - Moderately Agree
        - 1
    - Strongly Agree
        - 4

- **(8.3)** If the answer to 8.2. was any one of the three 'Agree' choices, was/were any of the company(ies) or non-profit(s) based in North Carolina?
    - Yes/No
        - 4

- **(8.4)** If Yes, which company(ies) or non-profit(s) *(Note: separate with commas)*:
    - List of Companies

- **(8.5)** Did this partnership lead to, or will it likely lead to, additional partnerships with the company(ies) or non-profit(s) on other projects?
    - Yes/No
        - 6

Outcomes

- **(9)** How many jobs per category, if any, did your company <u>create</u> with the <u>NC Green Business Fund Grant</u>? How many jobs per category, if any, did your company <u>retain</u> with the <u>NC Green Business Fund Grant</u>? You may use fractions of full-time effort (e.g., 1 full time employee plus 1 half-time employee=1.5 employees). Enter 0 in categories with no jobs. ***Note: Do not include jobs created or retained by other funding:***
- **Jobs Created:**
  - Professional/Scientific
    - Obs: 21
    - Mean: .476
    - StdDev: .512
    - Range: 0 to 1
  - Management
    - Obs: 21
    - Mean: .190
    - StdDev: .402
    - Range: 0 to 1
  - Technical/Technician
    - Obs: 21
    - Mean: .762
    - StdDev: 1.446
    - Range: 0 to 5
  - Skilled Labor
    - Obs: 21
    - Mean: 1.095
    - StdDev: 2.737
    - Range: 0 to 11
  - Unskilled Labor
    - Obs: 21
    - Mean: 0
    - StdDev: 0
    - Range: 0
  - Other
    - Obs: 21
    - Mean: .190
    - StdDev: .602
    - Range: 0 to 2

- **Jobs Retained:**
    - Professional/Scientific
        - Obs: 21
        - Mean: .619
        - StdDev: 1.322
        - Range: 0 to 6
    - Management
        - Obs: 21
        - Mean: .381
        - StdDev: .805
        - Range: 0 to 3
    - Technical/Technician
        - Obs: 21
        - Mean: .429
        - StdDev: .811
        - Range: 0 to 3
    - Skilled Labor
        - Obs: 21
        - Mean: .619
        - StdDev: 1.658
        - Range: 0 to 6
    - Unskilled Labor
        - Obs: 21
        - Mean: .286
        - StdDev: 1.102
        - Range: 0 to 5
    - Other
        - Obs: 21
        - Mean: .381
        - StdDev: 1.244
        - Range: 0 to 5

(10) If applicable, please give the number of patents and/or copyrights for the technology developed as a result of the NC Green Business Fund Grant. What is the estimated lifetime commercial value (if applicable) of each? *(Enter numbers. If none or unknown, enter 0)*

*__Intellectual Property Number (#)__
(Please provide number of)

- Patents Applied for but Pending
  - 9
- Patents Received
  - 2
- Copyright Applies for but Pending
  - 0
- Copyrights Received
  - 3

- *__Intellectual Property Value ($)__
  (Please provide estimated lifetime commercial value of)
  - Patents Applied for but Pending
    - Obs: 21
    - Mean: 3,809,524
    - StdDev: 1,190,000
    - Range: 0 to 50,000,000
  - Patents Received
    - 0
  - Copyright Applies for but Pending
    - 0
  - Copyrights Received
    - Obs: 21
    - Mean: 24,047.62
    - StdDev: 109,059.8
    - Range: 0 to 500,000

- **(11)** Has your company had any actual sales of products, processes, services or other sales incorporating the technology developed during this project? *Select all that apply.*

  *Sales
  - Although there are no sales to date, the outcome of this project in use by the intended target
    - 4
  - No sales to date, nor are sales expected.
    - 7 (2 Public)
  - No sales to date, but sales are expected.
    - 7
  - Sales of product(s), process(es), or service(s)
    - 8
  - Other sales (e.g., rights to technology, sale of spin-off company, etc.)
    - 1 (1 Public)
  - Licensing fees
    - 0

- **(12)** For your company and/or your licensee(s), what is the approximate dollar amount of total sales resulting from the technology developed during this project? If multiple grants (from other sources) contributed to the ultimate commercial outcome, report, to the extent possible, only the share of total sales appropriate to the project supported by this NC Green Business Fund Grant. If none, enter 0.

  Total Sales Dollars of Product(s), Process(es) or Service(s) to date.
  - Your Company
    - Obs: 21
    - Mean: 908,738
    - StdDev: 3,699,575
    - Range: 0 to 17,000,000
  - Licensee(s)
    - Obs: 21
    - Mean: 14,285.71
    - StdDev: 65,465.37
    - Range: 0 to 300,000

- **(12.2)** Select the most applicable response to the following statement: *The NC Green Business Fund Grant helped make the sales above possible.* (If no sales, select "Neutral"):
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
        - 13
    - Slightly Agree
    - Moderately Agree
        - 2
    - Strongly Agree
        - 6

- **(13)** For your company and/or your licensee, what is the approximate amount of total sales expected during calendar year 2012 resulting from the technology developed during this project? If none, enter 0.
    - Total sales dollars of product(s), process(es) or services(s) expected during calendar year 2012.
        - Obs: 21
        - Mean: 739,285.7
        - StdDev: 2,226,131
        - Range: 0 to 10,000,000
    - Other Total Sales Dollars (e.g., rights to technology, sale of spin-off company, etc.) expected during calendar year 2012.
        - Obs: 21
        - Mean: 51,666.67
        - StdDev: 172,795.6
        - Range: 0 to 750,000

- **(13.2)** Select the most applicable response to the following statement: *The NC Green Business Fund Grant helped to yield one or more of the expected sales types (13 a-b) above* (If no sales are expected, enter "Neutral"):
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
        - 11
    - Slightly Agree
        - 1
    - Moderately Agree
        - 4
    - Strongly Agree
        - 5

- ***(14)** What percentage of your company's revenue growth from the time of the NC Green Business Fund Grant award to now would you attribute to the NC Green Business Fund Grant?
    - <25%
        - 12
    - 25-49%
        - 6
    - 50-74%
        - 2
    - 75% or more
        - 1

Overall Perceptions

- **(15)** The NC Green Business Fund increases the intensity and quality of my organization's research and development efforts.
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
        - 1
    - Slightly Agree
        - 2
    - Moderately Agree
        - 5
    - Strongly Agree
        - 13

- **(16)** The NC Green Business Fund helps encourage the expansion of small to medium sized businesses with 100 or fewer employees that have innovative commercial technologies, products and services to grow a green economy in the State.
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
    - Slightly Agree
        - 2
    - Moderately Agree
        - 4
    - Strongly Agree
        - 15

- **(17)** The NC Green Business Fund is an <u>effective</u> program.
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
    - Slightly Agree
        - 2
    - Moderately Agree
        - 3
    - Strongly Agree
        - 16

- Please provide any additional comments you may have regarding the effectiveness of the program. Additionally, if the Program has helped you in a specific way not captured by the questions above, please elaborate.
- I allow my comments in this "Additional Comments" field to be shared with the NC General Assembly.
    - Yes/No

- **(18)** The NC Green Business Fund is an <u>efficiently managed</u> program.
    - Strongly Disagree
    - Moderately Disagree
    - Slightly Disagree
    - Neutral
        - 1
    - Slightly Agree
        - 1
    - Moderately Agree
        - 5
    - Strongly Agree
        - 14

- Please provide any additional comments you may have regarding the management of the program, including the Program staff with whom you have interacted.

- I allow my comments in this "Additional Comments" field to be shared with the NC General Assembly.
    - Yes/No