A Primer on R&D in the Energy Utility Sector

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National Regulatory Research Institute

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Executive Summary

Importance of R&D

For both an industry and the general economy, technological change is a key ingredient for growth and long-term prosperity. It can spawn new products or improvement of existing products or higher efficiency of production processes. Economists generally agree that technological change is a prerequisite for economic growth.

A precursor to technological change is investments in research and development (R&D). A major purpose of R&D is to advance the current state of technology.

R&D has three distinct stages: *Basic research* attempts to create new knowledge that will lead ultimately to profitable commercial applications of new technologies. *Applied research and development* uses the new knowledge created by basic research and applies it to products or services that society values. *Demonstration* helps to determine the commercial feasibility (e.g. feasibility at scale) of a new technology. In other words, basic research provides the theoretical foundation for new technological innovations, while applied research, development and demonstration focuses on the feasibility of new technologies for practical and commercial applications.

The inherent features of R&D pose challenges for a private for-profit company. It is expensive, for example, with costs commonly incurred several years before a company can reap profits or other benefits. R&D by nature is risky and success is difficult to predict. Innovations originating with R&D often require long lead times between basic science and commercial deployment. External parties, e.g., competing companies, can also appropriate the benefits. New knowledge is especially appropriable, unless one has acquired patent protection. These features of R&D imply two things. First, companies are unlikely to innovate unless the payoff from successful innovation is substantial. Second, the market may under-allocate resources to R&D, providing a rationale for government funding.

The public sector complements R&D by the private sector, which rationally disregards R&D that would be in society's interest but not profitable for a company. Sources of this market failure include (1) public goods (e.g., national security and less dependence on foreign oil), (2) externalities (e.g., unpriced and unregulated environmental effects), (3) economic factors (e.g., less than full appropriability of the research results, the size of the risk, and (4) the length of the time horizon before potential gains translate into profits.

Concerns over R&D in the energy/utility sector

The U.S. has seen a decline over the past several years in the level of R&D funding (in real dollars) in the energy industries by both government and the private sector. Private firms have also shifted their R&D dollars toward short-term projects with an expected rapid payback. Many prominent observers have warned that the downward trend in R&D could have a high social cost; for example, the slowing down of the economy's long-term productivity and growth, since technological change is the engine of economic growth. For non-regulated firms, technological change is the key element for long-term financial sustainability. For regulated utilities, technological change is critical for advancing long-term regulatory and public-policy objectives, like safety, reliability, cheaper energy, increased energy efficiency and a cleaner environment.

As the case study for this paper, the natural gas sector has encountered drastic cuts in R&D investments largely because of the combination of industry restructuring, loss of funding for collaborative industry R&D and the decline in government funding for R&D. These factors taken together have caused a sharp drop in R&D investments over the past two decades. The lost opportunities from the potentially high returns from R&D investments, ultimately, deprive benefits to utility customers and shareholders, the environment and society at large. One indicator of this concern is the small size of R&D expenditures (as a percentage of industry revenues) and the potentially high gains from well-defined, cost-effective R&D projects. It is a topic that has received scant attention in regulatory circles.

Addressing these concerns involves state utility regulation. Declines in R&D in the energy utility industries mirror the energy sector as a whole. A number of studies have warned that this trend will slow down the pace of new technologies to achieve public-policy goals such as clean air, economic growth and the competitiveness of the U.S. in the world market.

The role of public utility regulation

Various features of public utility regulation affect how much and how utilities conduct R&D. They include the tightness of regulation, regulatory commitment, degree of information symmetry, cost recovery, allocation of the benefits, and risk incidence. For example, depreciation policy can help to ensure recovery of invested funds over the economic life of the physical capital. When depreciation rates are too low, with depreciation stretched out over too many years, a utility may find it uneconomical to replace old equipment will new equipment. The costs would be particularly high in a dynamic environment in which new technologies offer significant benefits to society. Allowed deprecation rates can therefore have a significant effect on R&D and technological progress.

As another example, a regulatory practice of splitting the benefits of a new technology between utility customers and shareholders can boos the efforts of utilities to invest in R&D. A third example is the regulatory commitment to R&D, reflected in guidelines, rules or individual rate-case decisions, can lower the risk to the utility, thereby making R&D more attractive.

The economics literature has devoted relatively little attention to regulated firms' incentive to engage in R&D, and develop and adopt new technologies. Nevertheless, the standard narrative is that regulation causes utilities to be cautious about innovating and taking risks. The common thinking is therefore that utilities fall short in their R&D activities and deployment of new technologies. Utilities would tend to underinvest in R&D and new technologies that have public benefits or threaten their monopoly status. For the latter reason in particular, regulators need to be vigilant that utilities do not "squash" those technologies that threaten their financial health but are in the interest of their customers.

This paper emphasizes the need for regulators to evaluate the effectiveness of R&D funded by utility customers: Are customers getting bang for their buck? How can utilities improve the net benefits of R&D funds? Regulators should be vigilant about utility R&D activities, both with regard to the level of funding and the allocation of funds. After all, R&D involves utility expenditures that, similar to others, require regulators to oversee their prudence.

Scope of the paper

This paper covers a wide range of topics relating to R&D that are pertinent to state utility regulators. Its primary purpose is to educate regulators on the various aspects of R&D. The topics include the following:

(1) The meaning of R&D and its importance to private firms and the general economy;
(2) The economic factors driving firms to invest in R&D;
(3) Market and regulatory barriers to R&D;
(4) The role of government in supporting R&D;
(5) The effect of state utility regulation on R&D, not only the level but also the kinds of projects undertaken; for example, regulatory incentives for R&D activities;
(6) An overview of R&D in gas distribution;
(7) Likely obstacles to R&D by utilities; and
(8) Special actions that state utility regulators can take to stimulate R&D.

This paper does not definitely answer the question of whether public utilities are spending too little on R&D. After all, coming to such a conclusion would require more information than what this paper could provide. For example, it would require not only a complex technical assessment on an individual utility level, but also a value judgment about the social desirability of both private and public R&D initiatives. It may well be true that some utilities are undertaking adequate R&D while others are not. Looking across all utilities, however, based on the trends and other evidence, one could conjecture whether or not utilities are spending enough on R&D. Overall, the evidence suggests that speedier action on a larger scale would be in the public interest.

The goal of this paper is to leave the reader with three thoughts. First, R&D plays a vital role in society that is often overlooked by policymakers. Second, the concern that the U.S. is spending too little on energy R&D seems very real. R&D is a hard sell to both the private sector and government, particularly as our society has become more myopic and less patient for benefits farther out than immediate or short term. Third, utility regulators should revisit their practices for providing utilities with incentives to encourage innovation and R&D. One broad approach under the control of state utility regulators is to change the risk-reward relationship so that utilities have greater motivation to innovate. As the electric industry transforms, a potentially significant benefit can come from utilities optimally integrating new technologies into their distribution system. This integration will likely require ingenuity and innovation, bolstered by robust regulatory incentives.

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A Primer on R&D in the Energy Utility Sector

Research and development (R&D)[1] is a precursor for the long-term development of new technologies and other innovations (e.g., a change in the utility business model) that can lead to greater societal welfare.[2] Demand for R&D is therefore a derived demand for improved products and processes that are commercially profitable or achieve some public benefit more effectively or at a lower cost.

Although innovation is difficult to measure, studies have shown that R&D spending is a critical input into innovation.[3] Another indicator of innovation that researchers often use is the number of patents granted annually.[4]

The main benefit of R&D is to advance the current state of technology. In the public utility sector, technological change has the additional value of fostering policy objectives. For some industry observers, the absence of breakthroughs in energy technology will preclude major strides toward attacking global warming in an affordable way.[5]

Technological change is probably the most important factor for improving the long-term performance of public utilities, which after all is the prime objective of regulation, along with assuring just and reasonable rates. It is driving today's dialogue on utility business models,[6] the

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[1] This paper uses the term "R&D" to include demonstration, which has the important function of showing whether a new technology or other innovation is feasible on a commercial scale. Some organizations and writings use the term "RD&D" to more explicitly convey demonstration as a research activity. As discussed later, demonstration of new technologies may be the most important R&D function of utilities.

[2] Innovations can include hardware, software, management and other practices, or just new knowledge that enables the production of new products or services, or more efficient production of existing products or services.

[3] Council of Economic Advisors 2016, Chapter 5.

[4] The link between patent grants and aggregate productivity growth, which is a major contributor to economic growth, is tenuous, since the number of patents depends on several factors. *See*, for example, Council of Economic Advisors 2016, Chapter 5; and Griliches 1988.

[5] As a peculiarity, innovations to combat global warming have the purpose of preventing our quality of life from deteriorating, rather than the normal "innovation" objective of improving it.

[6] By revamping their business model, utilities could embrace, accommodate (for third parties) or invest in new technologies to better serve their customers. It could also move the industry toward achieving broader public policy goals. One rationale for a changed business model is that technological and economic dynamics have affected utility sales and revenues to the degree that the status quo inevitably will (a) lead to an unsustainable financial outcome for utilities and (b) fail to allow utility

regulatory paradigm and ratemaking, market developments and public policy. Technology typically has its genesis in R&D, at the basic level of creating new knowledge that ultimately leads to commercial viability of a new technology or other innovations.

There is widespread concern over the possibility of inadequate public-funded R&D in the future because of government budgetary pressures. Another worry is that R&D in the energy industries is greatly underfunded, unable to address global warming and other challenges facing the U.S.[7]

A major focus of this paper addresses the effect of regulation on utility-funded R&D and on the opportunities for third-parties to disseminate their new technologies to retail electric and natural gas customers. Compared to most other industries, energy utilities spend an extremely low portion of their revenues on R&D. Since restructuring of the electric and natural gas industries, collaborative research by energy utilities has declined sharply. Collaborative research has been an important part of R&D in the energy utilities industries, with documented benefits to consumers and society at large.

A number of NARUC resolutions over the years show support for R&D by state utility regulators. Specifically, they reflect official NARUC's endorsement of national collaborative R&D; natural gas R&D programs that accelerate development of low greenhouse gas-emitting technologies; public purpose R&D; the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI) and its successor, the Gas Technology Institute (GTI) as R&D management organizations; R&D tax credits[8]; and research institutions in general.[9]

I. The Vital Role of R&D in Society

A. Contributor to economic growth

Innovation, which includes technological change, is a key component of economic growth and long-term prosperity. Without R&D to spawn new technologies and other innovations, economic growth would stagnate. Major repercussions are less improvement in the

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customers to reap the full benefits of new technologies. Despite this daunting challenge, utilities possess many relevant resources and capabilities, including access to new technologies, placing them in a position to adapt and thrive in an increasingly competitive environment. *See*, for example, AEE Institute 2015; Institute for Electric Innovation 2015; and Costello 2015.

[7] *See*, for example, American Energy Innovation Council 2015 and 2013; Anadon et al. 2011; and Greenstone 2011.

[8] Tax credits reduce the after-tax costs of R&D activities. The government considers them as forgone revenue, or more commonly called tax expenditures.

[9] *See* two of these resolutions at National Association of Regulatory Utility Commissioners 1999 and 1994.

citizenry's standard of living and higher costs for the attainment of policy goals established by society. Economists of all stripes have recognized this for decades.

Dynamic efficiency in the form of technological change is a vital stimulant for a growing economy; technological change almost always comes after previous R&D efforts to gain the knowledge required for creating new products or production processes.[10] Innovation typically follows the sequential pattern of new knowledge, testing and refinement.

Economists have long held that technological change is a major factor of total factor productivity (TFP) growth in the economy.[11] They have conducted extensive research on the relationship between the growth of TFP and R&D. That is, the so-called residual growth factor in production, unexplainable by increased inputs (labor, capital, material), measures in part the outcome of R&D that triggers technological change.[12]

R&D can create new and improved products and services, or higher efficiency of production processes. It has also led to innovations in the organization and management of businesses. A new utility business model, for example, can be a form of innovation that increases the welfare of utility customers as well as society as a whole.

B. Fostering public policy objectives and utility performance

1. A new electric industry

In the public utility sector, technological change has the special benefit of advancing public policy objectives, namely, safety, reliability, energy security, higher energy efficiency, affordable energy services and a cleaner environment. With innovations, for example, electric utilities can improve their cyber security more effectively and at a lower cost.

Many experts are predicting a transformation of the electric industry from where the utility is an infrastructure and commodity provider to being a platform and service provider; that is, a change from a rigid, unidirectional and centralized system to a more flexible, networked system. The transformed industry will feature a dynamic, information-based interactive system. Utilities would assume the function of coordinating the flow of electricity on their systems so as to accommodate power flowing through multiple paths and maximize customer value. New technologies can help to achieve this outcome more economically. In this new world, innovations that create products and services offering customers greater convenience, control,

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[10] R&D represents investment in knowledge. This knowledge can turn into a new technology that in turn improves productivity. New knowledge is therefore an enabler of new technologies and other innovations. Knowledge embodies a public good: if someone produces knowledge, others can benefit from it without paying for it (i.e., others are "free riders"). Thus, the person producing it will not be able to collect the full value of the knowledge she created.

[11] By definition, total factor productivity measures output per unit of aggregate input. Inputs include labor, capital, materials and other economic resources required to produce a good or service.

[12] *See*, for example, Griliches 1988. Education is another important factor affecting TFP.

value and participation will be in demand. The emphasis on consumer empowerment will entail new, value-added services, new pricing options, self-generation, choice of electricity sources, and real-time information. The question then turns to, how can innovation facilitate these developments?[13]

A new business model could help electric utilities to embrace, accommodate or invest in new technologies to better serve their customers. An increasingly important function of regulated public utilities will be to act as a conduit in filtering the benefits of new technologies developed by third parties to retail customers. After all, most new technologies that benefit utility customers had their beginnings outside the utility space. The ability and willingness of utilities to play the role of new-technology adopter depend importantly on regulators creating a favorable risk-reward environment.[14] If utilities feel that new technologies will not improve their financial condition, they will be less inclined to adopt them for the benefit of their customers.

2. R&D versus subsidies

By definition, disruptive technologies, which begin with R&D, allow new or existing products and services to become more affordable to a broader population. They also overwhelm the established technologies. They can therefore affect how businesses operate and their internal organization.[15] Frequently, they require companies to abandon their old business practices and reinvent themselves for success and survival.

One reasonable view is that accelerating R&D instead of subsidies is a better approach to making clean energy resources economical and acceptable in the long run. Another important action will be to hold participants in the energy market accountable for the adverse effect of greenhouse gas emissions. By requiring companies to internalize emissions and their damage to health and the environment, clean energy will become more competitive with fossil fuels, in the process stimulating more R&D spending on clean energy.[16]

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[13] Some observers see as inevitable the transformation of the electric industry from a rigid, unidirectional centralized system to a more flexible, networked system. *See*, for example, AEE Institute 2015; and Institute for Electric Innovation 2015. While this transformation may occur, the timing and extent of its presence will vary by state and utility. Some states (e.g., California, Hawaii and New York) will be leaders while others will follow.

[14] Part VI will expand on ways regulators can achieve this. As an adopter, the utility does not have to be the creator of a new technology; it can simply acquire and use the technology for the benefit of its customers.

[15] Technological change is a major source of changing market structures, as regulated firms move into unregulated markets, and vice versa.

[16] Some countries and U.S. states are experimenting with different ways to price carbon. The objective is to create incentives for development of new energy solutions while also giving energy companies adequate certainty to invest in zero-carbon sources. Subsidies protect consumers from the true cost of a product or service. Energy subsidies are prevalent throughout the world, covering fossil fuels as well as renewable energy. Economists consider most subsidies as inefficient, often politically motivated

C. Causes of new technologies

For the electric industry, a confluence of new technologies is erupting on the scene. The most important ones include solar, wind, battery storage, electric vehicles, fuel cells, small modular nuclear reactors, digital control of the grid, smart technologies, demand-side innovations, and information and communications technologies. Some of these technologies will require a longer time before they become commercialized. Others that show technical promise today may never attain commercial success.

Different factors account for the emergence of new technologies. They include public policy, customer demands, favorable supply-side developments, rent-seeking, ideology, and synergy where one technology development spawns others. Public policy has become more aggressive in recent years, especially in meeting clean air and energy efficiency objectives. Many customers are demanding real-time information and access to the latest technologies. Reduced costs for renewable energy have been impressive. Some technologies have received special favors because of vigorous lobbying by their advocates. The emergence of some technologies has led to advancement in others; for example, the pairing of solar and storage, of batteries and electric vehicles, and of the modern grid and distributed generation and other new technologies. Because some of these motivators for new technologies may be antithetical to a better society, regulators and other policymakers must exercise vigilance in placing their bets on certain technologies even when they seem compatible with clean-energy objectives or other goals in vogue.

Some of these technologies may inflict a disruptive effect on the electric industry, but as of now their effect is unknown. While many new technologies in the electric industry might have a bright future, we are unable to go beyond guessing whether they will eventually succeed on a broad scale.[17] For example, the joke that fusion is 30 years away from commercial viability, and always will be, has some truth. Some new emerging technologies may appear promising only because of subsidies and an excessive push by influential interest groups and policymakers. R&D can play a critical role in nurturing new technologies during their initial stages of commercial application so that they become more prominent in the future. When a new technology or other innovation becomes commercial, it can still benefit from further R&D to hasten its diffusion in the marketplace.

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and enduring too long. Their preferred option is to have the government reallocate funds from subsidies to basic research.

[17] Initial flaws and high costs of new technologies require an extended period of experimentation, learning and technology development as part of the "innovation" process. Widespread adoption of a technology often follows this extended period during which the technology is iteratively tested, refined and adapted to market conditions. As expressed by one technology expert, new technologies are attractive but generally too expensive for the mass market. When first entering the market, new technologies are "crude, imperfect, and expensive." They initially assume a market "niche" from their performance and unique features, rather than by their cost competitiveness.

II. R&D 101

Understanding the economics and policy implications of R&D requires identifying its several characteristics, some of which are unique to this activity. The first, as just mentioned, is that R&D is the major driver of technological innovation. According to one definition,

> Innovation is the search for, and the discovery, development, improvement, adoption and commercialization of new processes, new products, and new organizational structures and procedures.[18]

Innovation consists of two broad actions: (1) creating new ideas and (2) implementing them in practical applications for financial profits or broad societal gains. One should not underestimate both the importance of innovation and the commitment and resources required to go from basic new knowledge to deployment on a large scale. Innovation is neither costless nor risk-free. The majority of innovation projects end up in failure.

Second, R&D has three distinct stages: Basic research, applied research and demonstration. *Basic research* attempts to create new knowledge that will lead ultimately to profitable commercial applications of new technologies. *Applied research and development* uses the new knowledge created by basic research and applies it to products or services that society values.[19] *Demonstration* helps to determine the commercial feasibility (e.g. feasibility at scale) of a new technology.[20] In other words, basic research provides the theoretical foundation for new technological innovations, while applied research, development and demonstration focuses on the feasibility of new technologies for practical and commercial applications.

Third, R&D has public benefits that justify funding from taxpayers.[21] Government support is essential for high-risk, early-stage R&D where public benefits are broad-based but uncertain. These benefits are external to a company and defined by economists as positive

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[18] Shy 1995, 221. Innovation involves activities that span invention, commercialization, and ultimately deployment of new technologies and business processes. Each of these activities is essential and requires special skills for which the business sector, nonprofit groups or the government might have a comparative advantage.

[19] Most applied research arises from the pursuit of profit, taking into account the cost of R&D.

[20] Many analysts consider demonstration as a legitimate government function in showing a new technology to be feasible on a commercial scale. They exclude from the definition of "demonstration" those activities focusing on deployment of the technology, as most analysts would contend this is properly a private-sector function. *See*, for example, Deutch 2011; and Greenstone 2011.

[21] The value of R&D for private companies relates to profitability. Since private returns from R&D understate true social returns from such investments, R&D will be underprovided. Thus, there exists an economic rationale for taxpayer-funded R&D. Overarching analyses of the returns from investments in innovation generally demonstrate that benefits to society and utility customers substantially outweigh the costs of innovation investments.

externalities.[22] Examples include clean air and national security, outcomes that are important for the country but not directly for individual companies in terms of their profitability.[23] Investments in new technologies that reduce greenhouse gas emissions and lower the risk of harmful climate change, for example, yield benefits for society at large. Absent carbon pricing or similar policies, no direct financial compensation associated with those benefits exists, thus driving a wedge between the private returns that a company can realize from such innovations and the overall social return. When the government gives companies incentives (e.g., carbon tax) or imposes mandates, on the other hand, clean air can translate into higher profits for companies.[24] The policy challenge then turns to identifying the optimal government incentives for private sector R&D and innovation.[25]

Fourth, for many companies, survival depends on maintaining a technological edge over competitors. Industries such as the pharmaceuticals, computer software/hardware, and mobile phones are especially prone to fierce competition. If a company falls behinds its competitors, it could mean financial disaster as customers switch to those companies with the latest technologies and highest product quality.

Fifth, companies are often users of new technologies rather than creators. For example, they tailor new technologies created by others to their specific needs and situation. Public utilities, historically, have not been prolific inventors of new technologies. Instead, they commonly integrate into their network new technologies developed by third parties.

Sixth, the attainment of public policy goals at tolerable cost to society frequently requires technological breakthroughs. Many experts assert that making the transition to a low-carbon

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[22] Public-benefit R&D involves goods and services that benefit society, but for which private interests cannot capture enough revenues to recover the cost (plus a profit) of providing the goods and services (e.g., space exploration). In addition to providing a variety of services to promote the creation, development, and commercialization of new technologies, say, for energy efficiency, public-benefit R&D can address market failures that persist in the energy-services sector.

[23] Government-funded R&D projects face the challenge of allocating funds to projects with the highest potential social payoff; that is, funding decisions based on an independent, peer-reviewed process, rather than politics. Industry executives have criticized certain government-funded R&D programs for favoring technologies with the most political appeal, but not necessarily have the best commercial and technical potential. In general, DOE funding decisions have not been as single mindedly based on peer review as is the case with the National Institutes of Health and NSF. Although most economists believe that government plays a vital role in R&D, many are skeptical that it can do so efficiently and in the best interest of society. The problem also exists that public R&D may crowd out private R&D, especially during the development and demonstration stages. *See*, for example, U.S. Government Accountability Office 2008.

[24] By violating a mandate, for example, a company could pay a large penalty that would exceed its costs of complying with the mandate.

[25] Public supported energy R&D includes DOE's Energy Frontier Research Centers (basic research), national laboratories, universities, applied R&D programs, large-scale demonstrations, loan guarantees, tax credits, and industry grants and partnerships.

future at an affordable cost, for example, will demand such breakthroughs. Pertinent to the utility sector, R&D is essential for advancing long-term policy objectives mentioned earlier, namely, safety, reliability, cheaper energy, improved energy efficiency and a cleaner environment.

Seventh, basic research does not attempt to solve an immediate problem or create a new product. Benefits are long term in nature and highly uncertain. Government funds close to half of basic research, with over 60 percent of it conducted by universities and non-profit groups (*see* Table 1). Private companies typically steer away from basic research, as the benefits are too speculative, appropriable and highly uncertain. Firms view R&D from the perspective of profit expectations, therefore concentrating on the end stages of R&D.[26]

As Table 1 shows, the business sector focuses most of its efforts on applied research and development. One major source of information on U.S. R&D spending comes from a survey conducted by the National Science Foundation (NSF). NSF defines the three stages of R&D as the following: (1) *Basic research* is "systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind"; (2) *Applied research* is "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met"; and (3) *Development* is "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."[27] These definitions correspond closely to those used in this paper. The federal government, in contrast, allocates most of its funding to the earlier.

Table 1: Share of Funding and Performing Sources for Different Stages of Research, 2013

	Basic Research	**Applied Research**	**Development**
Business Sector	35.3% (24.2%)*	55.2% (56.3%)	80.9% (88.4%)
Federal Government	47.0 (11.8)	36.8 (16.6)	17.8 (8.9)
Other entities (e.g., universities, nonprofit groups)	17.7 (64.0)	8.0 (27.1)	1.3 (2.7)

Source: National Science Foundation
* Performing sector in parentheses

[26] Firms tend to conduct their R&D, for example, on "applied" projects where the payoff to them is more certain and immediate. Research that is costly and has a high chance of failure may exceed the risk threshold of the private sector, even though from a societal point of view having a certain number of such projects in the national R&D portfolio is beneficial because occasional successes can bring very high gains. Research that will take a long time to complete is also likely to fall short of the private sector's requirement for a rate of return attractive to investors, even if confidence of success is high.

[27] Another popular source is the American Association for the Advancement of Science (AAAS). *See*, for example, http://www.aaas.org/news/primer-recent-trends-federal-rd-budgets. One noteworthy statistic is that the business sector spends 80 percent of its R&D dollars for development.

Eight, R&D intensity varies widely across different industries. The average intensity for industrial companies, measured as R&D expenditures per unit of net revenues, is 3.3 percent. The intensity across industries spans a wide range. As shown in Table 2, industries expected to have high intensities (for example, pharmaceuticals and computer software/hardware) are under constant pressure to develop new products. Others where technological changes are less urgent have, not surprisingly, had much lower intensities. Especially conspicuous is the extremely low intensity of utilities, 0.1 percent. As discussed later, whether or not this should be a concern requires much more information. For example, to what extent are outside entities able to supply new technologies to the utility sector that their customers desire?

Table 2: R&D Intensity for Different Industries, 2013

Industry	R&D Intensity (R&D Expenditures/Net Revenues)
All Industries	3.3%
Manufacturing	3.8
Chemicals	4.5
Pharmaceuticals and medicines	10.3
Automobiles, trailers and parts	2.4
Computer and electronic products	10.6
Electrical equipment	2.9
Non-manufacturing industries	2.7
Software publishers	9.0
Computer systems design	8.4
Finance and insurance	0.7
Utilities	0.1

Source: National Science Foundation

Ninth, innovation spawned by R&D requires the right incentives as well as trial and error.[28] R&D is inherently risky. Most R&D efforts end up as "dry holes.[29] In a dynamic world, R&D for one technology can quickly become obsolete with the introduction of newer, more promising technologies.[30] Uncertainty is an inherent feature of innovation. While all

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[28] Firms tend to engage in R&D only when results are appropriable and offer rates of return greater than other less-risky investment options.

[29] This means that regulators should expect a utility's portfolio of research projects to have some failures. As long as the utility initiated and managed them prudently, it should not be held responsible. That is, the utility should be able to pass through all the costs to customers, under the added assumption that the projects' benefits would have mostly gone to customers.

[30] Promising new technologies can quickly fizzle, for example, as market conditions change, or as subsidies are taken away.

investments carry uncertainty, the level associated with the returns to investment in innovation is often particularly high. Not only is the variance of the distribution of expected returns much higher than for other investments, but commonly much of the value may be associated with very low-probability but very high-value outcomes.[31] Uncertainty may prove to be a particularly serious problem for environmental policy: The technologies needed to comply with proposed regulations may evolve in unexpected ways once a policy is in place, making it difficult for regulators to anticipate the true costs of compliance.

Because of the uncertainty of outcomes, firms and society should pursue a number of diverse approaches. A portfolio approach to R&D projects therefore seems sensible in comparison with placing all bets on a single project. A later discussion provides a more detailed rationale for diversification of R&D projects.

Added to the risk of R&D is the fact that external parties can also become “free riders” by appropriating the benefits. For example, new knowledge is easily appropriable, unless a company acquired patent protection. These features of R&D imply two things. First, companies are unwilling to innovate unless the payoff from successful innovation is substantial (which often comes from being first[32]). Second, the market may under-allocate resources to R&D, providing a rationale for government support. Both conservative and liberal economists acknowledge that a major function of government is to fund basic research. Studies have confirmed that social returns on R&D are much greater than private returns, evidence supporting government involvement (e.g., via funding or performance) in R&D.[33]

Tenth, R&D initiatives derived mostly from either *technology-push or demand-pull* incentives. An example of the first is entrepreneurs' desire to provide new goods and services, even in the absence of consumers expressing their desire for them.[34] An example of the second is the market desire to pull technologies through the development process to satisfy the demands

[31] *See* Scherer et al. 2000.

[32] An early adopter (i.e., a first-mover) has to make a trade-off between additional costs and potentially higher benefits (e.g., acquiring a patent). For example, leaders can reap higher profits but often incur higher costs than later adopters because of learning by doing and scale economies. “Learning by doing" means that over time firms make fewer mistakes, with production costs falling as a consequence. Because first movers may not capture all of the benefits from this experience—with some of those benefits going to rivals—this "spillover" effect would tend to underallocate resources to R&D.

[33] *See*, for example, Hall 2009; and Tyson and Linden 2012.

[34] A technology push implies that a new invention passes through R&D, production and sales onto the market without proper consideration of whether or not it satisfies a user need. An entrepreneur takes the risk that consumers, for example, will want a new product when offered to them even though they have not expressed any explicit desire for it. One example is the NEST thermostat, providing customers with a positive experience even though customers never expressed a prior demand for it.

of consumers and society in general for new goods and services.[35] There has been substantial research on the drivers of R&D.[36]

Last, several minefields stand in the way between basic research and the wide acceptance of a new technology or other innovations; it is a long arduous process;[37] most new technologies enter the world in a very primitive condition, with refinements often requiring further R&D and experimentation. Many if not most major innovations were not projected to have a huge impact (think of the airplane, TV, steam engine, computers, laser, mobile phones)[38] The public-good nature of R&D, the not-immediate returns, and the high uncertainty over the outcomes are all major obstacles to innovation by the private sector.

III. Salient Facts and Observations on R&D

The following list highlights major statistics on R&D together with observations from experts and other sources. Overall, it conveys a sense of concern about the R&D situation in the U.S. and implicitly argues for more funding and aggressive effort toward R&D.

(1) The decline in federally-funded R&D can spill over to private funding of R&D.[39] Fewer dollars for basic research, for example, translates into diminished R&D

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[35] Pioneered by Schmookler (1966), the demand-pull hypothesis emphasizes demand-side factors, such as consumers' demand for new products, and cost-reductions as primary drivers of R&D. The supply-push hypothesis, on the other hand, focuses on supply-side factors, such as differences in the technological environment of the company and industry concentration, leading to variations in R&D expenditures across companies. [Rosenberg 1974.]

[36] *See* Cumming and Macintosh 2000. Empirical evidence suggests that neither hypothesis alone can explain private sector R&D behavior: both demand and supply aspects are important. *See*, for example, Jaffe 1988 and 1986; and Pakes and Mark Schankerman 1984.

[37] Often it is not a linear process, but an iterative one with a reversal to previous stages as the technology evolves. The stylized innovation chain is as follows: from knowledge creation (basic science to lab work and experimentation) to prototypes and demonstrations, to commercialization and finally to deployment on a large scale. Innovation is a lengthy endeavor with the innovation process itself constantly iterating back and forth.

[38] As Bill Gates once remarked, people tend to overstate the short-term impact of new technologies and understate the long-term impact.

[39] As stated in the Council of Economic Advisors (2016, 223) report to Congress:

> The Federal Government is the majority supporter of basic research—the so-called "seed corn" of future innovations and industries that generates the largest spillovers and thus is at risk of being the most underfunded in a private market—and, as such, the Administration's efforts have prioritized increasing Federal investments in basic research while also pushing for an overall increase in Federal R&D investment.

investments, over time, for applied research and development, which the private sector predominantly carries out.

(2) There has been a shift toward short-term R&D projects with rapid payback.[40]

(3) The three stages of R&D defined by the NSF (basic research, applied research and development) differ widely in the composition of funding sources and performance sectors (*see* Table 1).

(4) Funding of R&D in the business sector comes from different sources: Individual companies, joint industry companies, vendors and manufacturers, and government.

(5) We have seen a decline over time in the level of R&D funding (in constant dollars) by the federal government.

(6) Total R&D intensity (public plus private) has been relatively stable over the past three decades at roughly 2.5 percent of Gross Domestic Product (GDP).[41]

(7) The share of private R&D has increased, over time, while the share of public R&D has fallen, from about 2.2 percent of GDP in 1964 to about 1 percent today.

(8) After 1980, small firms rivaled and even surpassed large firms in terms of R&D intensity (i.e., R&D/net revenues). The willingness of firms to undertake R&D depends on market structure; that is, competitive, monopolistic, or oligopolistic. One school of thought is that concentrated industries are more conducive to R&D activities.[42] Proponents often point to the Bell Labs, AT&T's research affiliate which was the source of major discoveries, including the transistor and the laser.

(9) In absolute dollars, the U.S. is the largest R&D investor in the world, with a share of about 30 percent of world R&D spending in 2014. As a percentage of GDP,

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[40] The trend is for corporate R&D expenditures to move toward shorter-term, quicker-payback projects in line with near-term business goals.

[41] *See*, for example, Bernanke 2011.

[42] Substantial market concentration can encourage innovation for at least two reasons. First, the profit a monopolist receives can be a source of R&D funding. Second, the prospect of substantial monopoly profit can be a compelling reason to undertake R&D investment. [*See* Schumpeter 1950; and Loury 1979, for example.] Schumpeter contended that an unregulated monopoly market creates the best environment for innovation. His reasoning was that a high payoff would come to those who could successfully innovate to keep out potential competitors. Another view is that monopolies have little incentive to innovate, but the prospects for a monopoly create a strong incentive to innovate.

The benefits of innovation to individual firms tend to be negatively related to the number of competitors. As the number of competitors increase, rival duplication of the innovation would be quicker, thus reducing the benefits to the innovator. Taken to an extreme, excessive competition could stifle the incentive of firms to innovate. Innovation creates profits for the owner, but also destroys profits for other firms, thus the Schumpeterian term “creative destruction".

however, the U.S. ranks 10th in R&D among member countries in the Organization for Economic Co-operation and Development. [43]

(10) Most of the other economies in the top 10, but not the U.S., continue to expand their R&D investments from private and public sources faster than their economic growth.[44]

(11) Because of the federal budget situation, we can expect lower financial support for R&D from the federal government in the future; entitlement programs in particular will comprise a larger share of the budget, which means less money for education, infrastructure and R&D.

(12) R&D is vulnerable to budget cuts, by both the government and business sector, since its payoff is long term in nature and difficult to quantify.

(13) Many observers have expressed concerns over the downward trend in government-supported basic research that will affect future innovation. Basic research has large spillovers and because it produces results only in the distant future, it is extremely risky; thus, the private sector is unlikely to pick up the slack.

(14) R&D can improve the U.S. future energy situation. According to one expert, substantially increasing the government's focus on R&D, and specifically energy R&D, will meaningfully impact two significant long-run problems facing the United States today. Both our dependence on fossil fuels and economic competitiveness are issues that cannot be resolved through short term solutions, now or in the future. By increasing funding for energy R&D (and R&D in other areas), the United States can start planting the seeds of innovation that will grow into new technologies that we cannot imagine yet, but will potentially reshape our energy landscape and place our nation as a leader in clean energy.[45]

(15) Some observers have expressed concern over the low level of R&D in the energy industry, especially in view of the Obama Administration's ambitious goals for reducing greenhouse gas emissions.[46] One report recommends that the U.S. triples

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[43] Council of Economic Advisors 2016, Chapter 5 (Figure 5-9).

[44] Ibid., 223, 225.

[45] Greenstone 2011, 11.

[46] *See* Anadon et al. 2011; and American Energy Innovation Council 2015. The first document commented that :

> Low investment in innovation seems to be particularly severe in the energy sector; firms from the energy sector spend a smaller portion of their revenues on innovation than do firms in a broad range of other industries. [61-62]

the amount it spends on energy-related R&D to better compete in the world market, enhance national security and promote clean energy at reasonable costs.[47]

(16) During 1953-1987, the real annual growth rate in federal R&D spending was 4.9 percent; during 1987-2008 it grew at just 0.3 percent, and during 2008-2013 it declined by 1 percent.

(17) The federal government funded most R&D before the 1980s; the share of business sector funded R&D rose relative to federal-funded R&D since the mid-1960s.

IV. R&D by Public Utilities

The Uniform System of Accounts (USOA) defines R&D as the following[48]:

> [E]xpenditures incurred by public utilities either directly or through another person or organization (such as research institute, industry association, foundation, university, engineering company or similar contractor) in pursuing research, development, and demonstration activities including experiment, design, installation, construction, or operation…This definition includes expenditures for the implementation or development of new and/or existing concepts until technically feasible and commercially feasible operations are verified…The term includes, but is not limited to: such costs incidental to the design, development or implementation of an experimental facility, a plant process, a product, a formula, an invention, a system or similar items, and the improvement of already existing items of a like nature; amounts expended in connection with the proposed development and/or proposed delivery of alternate sources of electricity; and the costs of obtaining its own patent, such as attorney's fees expended in making and perfecting a patent application.[49]

Pilot programs and prototype projects fall within the definition, but not commercialization activities. Promotions, advertising and consumer surveys all lie outside the definition of R&D, according to the USOA.

NARUC, as mentioned earlier, has passed resolutions endorsing R&D in the energy utility sector. At least on paper NARUC values R&D in fostering public policy objectives in addition to improving the long-term economic welfare of utility customers.[50] Successful utility

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[47] Bill Gates has commented that the world spends only a few billion dollars a year on basic research for zero-carbon energy. He recommends that it should be investing two or three times that much. *See* www.gatesnotes.com/Energy/Energy-Innovation.

[48] The USOA uses the term research, development and demonstration (RD&D).

[49] U.S. Government Publishing Office 2016.

[50] According to the U.S. General Accounting Office (1996,6):

> In 1992, the National Association of Regulatory Utility Commissioners recommended that utilities devote 1 percent of their revenues to R&D. In 1993, 6 of the 112 investor-owned utilities

innovation can advance utilities' technical performance, lower economic cost, increase commercial competitiveness, and produce a cleaner environment.[51]

Utilities are producers but more often consumers of innovation. They adapt new technologies developed by others to their specific needs and situation; or integrate a new technology developed by a third party into their system or operations.

A. Decline in R&D for the electric industry

Energy-utility industry R&D spending has declined in absolute dollars since the mid-1990s. One reason is that in responding to increased competition, utilities curtailed their internal R&D activities in addition to reducing their support for collaborative research managed by EPRI[52] and GRI.[53] With increased competition, utilities could less easily pass through R&D costs to their customers and appropriability became more of a concern (i.e., new competitors could "free ride" on the benefits of R&D conducted by an individual utility).[54] The incentives for utility R&D therefore changed negatively.[55] One study of the electric industry highlights the sharp decline in R&D from the different sources:

> From its highest level of $741 million (in 2000 dollars) in 1993, [total] R&D expenditure [by U.S. electric industry] declined to $193 million in 2000 - a drop of nearly 74%. For electric and electric equipment, total R&D as a percent of sales, has

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met that target, but since then all 6 have substantially cut back their R&D spending. In 1994, utilities on average devoted about 0.3 percent of their revenues to R&D.

51 Utilities would fail to find all of these outcomes attractive from their perspective. For example, a cleaner environment might result from renewable energy replacing fossil fuel plants, which utilities may have to write-off.

52 EPRI's research activities cover a wide range of projects related to the environment, generation, nuclear power, and power delivery and retail. Retail technologies include energy-efficiency hardware, smart appliances, electric vehicles, demand-response devices, and distributed energy resources. The EPRI website says that "RD&D [research, development and deployment] drives innovation...Innovation drives progress." The website also comments that:

> EPRI's Technology Innovation (TI) organization has been integral in leading the development of key technologies that have benefited the electricity industry in numerous ways. The organization focuses on stimulating innovation and developing enabling electricity technologies for adoption in a 5-10 year period. *(See* http://my.epri.com.)

53 This paper later discusses GRI and its successor GTI.

54 One study found that electric industry restructuring in the 1990s was responsible for an almost 79 percent decline in utility R&D expenditures. [Sanyal and Cohen 2008.]

55 It is not obvious why the movement toward competition would decrease R&D. Utilities might upgrade their R&D activities, for example, to improve their operating efficiency and better compete. On the other hand, they may scale down R&D costs as part of their strategy to manage costs.

declined from 7.9 in 1986 to 6.9 in 1996. The Department of Energy's funding has decreased by 3 percent between1993 and 1999. State electricity R&D funding has declined by 30 percent during the same period. R&D funding by the electric utilities has fallen by 33 percent to about $476 million between 1993 and 1998. EPRI's (Electric Power Research Institute) budget has also dropped by 71 percent because of fall in contribution from major utilities.[56]

The U.S. General Accounting Office also noted a sharp decline in R&D expenditure by the electric utility sector in the 1990s:

> Utilities, in an effort to cut costs in anticipation of a shift from a regulated electric power industry to a deregulated environment, are also reducing their R&D budgets, according to R&D managers, because of the expected increase in competition in the electricity market. The declines in state programs are due to reductions in major funding sources, including utilities' contributions.[57]

As shown in Table 2, R&D intensity for utilities is much less than for U.S. industries as a whole. Historically, utilities conducted much of their R&D through collaboration and outside vendors. Utilities have therefore depended on both internal and external R&D for technological change. Four major entities have performed R&D in the U.S. electricity sector — the electrical equipment manufacturers (such as General Electric), the investor owned utilities, the Department of Energy and EPRI. [58]

B. Challenges for the future

Industry-funded R&D may have to involve more basic research in the future, as the federal government (for the reasons given earlier) is likely to spend less on R&D than in the past. Private, non-utility groups have started to commit to spending large sums of money for basic research related to clean energy.[59]

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[56] Sanyal and Cohen 2008, 3-4. Some state governments, most notably California and New York, have established programs to advance "public interest" technology in electricity to substitute for the decline in utility R&D following both electric and natural gas restructuring. *See*, for example, California Energy Commission 2014; and Krebs 2006. In 1997, for example, California created the Public Interest Energy Research Program as part of electricity restructuring.

[57] U.S. General Accounting Office 1996, 2.

[58] As noted in one study, historically electric equipment manufacturers have conducted a significant portion of the R&D for the electric industry, as well as created much of the innovations in the industry. Compared to R&D expenditures by these manufacturers, utility-funded R&D was low, partially because utilities found it difficult to prevent "free riders" from reaping the benefits. Utilities allocated some of the R&D dollars to in-house research with the remaining monies allocated to external collaborative R&D entities, such as EPRI. [Sanyal and Cohen 2008.]

[59] Harvey 2016.

With the emergence of new technologies potentially transforming the electric industry, R&D becomes particularly critical. Many observers see the evolution of utilities from an infrastructure and commodity provider to an essential infrastructure and service provider. They believe that we are on the edge of significant breakthroughs similar to what we have seen in information technology.

Electric industry reform advocates talk about the inevitability of a new utility business model.[60] Within the confines of a business model, utilities could, first, ask what value they could create for their customers by unbundling services and making money on it (just like the airlines have done over the past several years). New services might start with R&D that ultimately leads to commercialization. Utilities might, for example, create new services demanded by distributed generation (DG) customers. With new technologies, utilities might be able to offer and deliver additional services. Utilities could also ask how they can deliver added value to their customers. For DG customers, utilities might have to create a "platform" that will allow those customers to purchase required distribution services. Again, a platform might require new technologies. The final question relates to how utilities can profit from these activities. They benefit, of course, only when DG and other customers value utility services more than the costs for delivering those services and utilities are able to price based on that value. Unless regulators allow utilities to profit from additional services, they will be reluctant to provide them.

R&D can provide a nudge to get certain technologies to commercialize sooner and on a larger scale. These technologies can play a critical role in the future development of the electric industry in: (1) facilitating the transition to clean energy, (2) transforming the power grid to be more digital, flexible, reliable and resilient and (3) individualizing services.[61] One sound economic argument is that more emphasis should fall on R&D and less on subsidies to promote new technologies that achieve specific policy objectives (e.g., clean air). The more efficient and effective approach would be to price pollutants and other externalities; that is, to give utilities and other entities correct price signals to stimulate R&D activity that will ultimately lead to new technologies and other innovations.

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[60] Different groups have expressed concerns over the current business model, namely, clean and renewable energy advocates, DG advocates, energy efficiency advocates and utility customer groups. Any new business model for utilities should (a) respond to new technological and market developments (b) support traditional regulatory objectives (e.g., cost-based rates, fairness across different customer groups) underlying "just and reasonable rates" and (c) satisfy predetermined broad public-policy goals. By operating under a new business model, for example, utilities could embrace, accommodate or invest in new technologies to better serve both their core and partial-requirements (e.g., DG) customers.

[61] *See* Institute for Electric Innovation 2015, 3-4.

V. Case Study for Gas Utilities

A. Draconian cuts in R&D funding

Government funding of gas distribution R&D is significantly less than for electric and potable water utilities.[62] The natural gas sector has suffered draconian cutbacks in government and industry-funded R&D over the past 15 years. The decline in DOE R&D funding earlier this century reduced the federal government's support for gas distribution infrastructure.[63]

As gas markets became more competitive, some pipelines pushed for the elimination of the mandatory mechanism to fund GRI.[64] Their efforts led to the phasing out of GRI's funding mechanism.[65] Shortly afterwards, the gas industry encouraged GRI and the Institute of Gas Technology (IGT) to combine their activities. In 2000, the GRI/IGT merger became official and today it is the Gas Technology Institute (GTI). The new organization conducts R&D in three broad categories: (1) Supply (expanding supply of clean, abundant and affordable natural gas), (2) delivery (ensuring a safe and reliable energy-delivery infrastructure[66]) and (3) end use (promoting the clean and efficient use of energy resources).[67]

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[62] American Gas Foundation 2007, 50 (Table 6.2). The lower funding for gas distribution is both in absolute dollars and R&D spending as a percentage of industry revenues.

[63] There are various DOE R&D arrangements: contracts with industry, work at DOE labs, grants to universities, and industry consortia (EPRI, GTI).

[64] GRI was founded in 1976 as a non-profit research management organization in response to the Federal Power Commission encouraging increased gas R&D to develop new sources of supply. It administered research funding provided by a surcharge on shipments of natural gas sold by the interstate pipelines. GRI represented a collaborative R&D model, subject to regulatory oversight, had an explicit public-benefit requirement (with regulators ensuring accountability) and focused on maximizing public benefits. At its peak in 1994, GRI administered funds in excess of $212 million. Its structure was similar to EPRI's, but FERC required it to review its program annually to provide for cost recovery from pipelines that choose to participate. Between 2000 and 2004, the surcharge was phased out. FERC-required analyses to determine the net benefits of GRI's programs to gas consumers and the public at large showed that GRI R&D programs were highly cost-beneficial. *See*, for example, American Gas Foundation 2007; Bournakis 2004; and Bournakis and Pine 2001.

[65] GRI emulates a collaborative R&D model under regulatory oversight and with a public benefit objective.

[66] For example, R&D can lead to more efficient and effective pipeline inspection and repair processes. The result is a decline in the cost and an increase in the chances of detecting leaks, with the consequence of economic, environmental and safety benefits.

[67] *See*, for example, Edelstein September 2015; and Johnson 2015.

Utilities in 29 states, as of this writing, are funding GTI, but at a much lower level than utility funding for GRI in the 1980s and 1990s.[68] For example, contributions today are around $14 million, which pales in comparison with funding levels of over $200 million during the early and mid 1990s.[69] This represents a decline of around 93 percent.

Gas utilities have a choice of (1) allocating their contributed funds across a set of portfolio projects managed by GTI or (2) devoting money to their own projects through GTI using membership contributions. GTI also has a Sustaining Membership Program where gas utilities fund longer-term, higher-payoff R&D projects via annual financial commitments.[70] GTI's governance model includes guidance from public-interest and other non-utility stakeholders. For example, GTI maintains a Public Interest Advisory Committee composed of public utility commissioners, consumer advocates, and environmental, economic, and academic experts.

Reduced levels of R&D funding have intensified the gas industry's challenges in dealing with aging delivery infrastructure, growing demand and the constant need to maintain high reliability and safety. Without adequate R&D and innovation, the industry will lose opportunities for improved pipeline safety, reductions in methane emissions, greater energy efficiency, and more efficient and effective pipeline inspection and repair processes. These potentially lost benefits could significantly damage the long-term performance of the industry from a societal perspective.

A legitimate policy question is then: Are current levels of R&D funds for gas distribution adequate? The absence of statistics on R&D funding for gas distribution makes it difficult to arrive at a definitive answer. As mentioned earlier, GRI funding peaked at over $200 million in the early and mid-1990s, with ratepayer-funded R&D managed by GTI currently being substantially less ($14 million). Compared with other industries conducting collaborative research, the natural gas industry seems to lag behind. Another statistic shows that GTI funding per gas customer is much less compared with the levels for organizations in other industries doing collaborative research.[71]

The great success stories in natural gas R&D would start with hydraulic fracturing ("fracking") becoming cost-effective and practical after decades of research and experimentation. R&D was also a key part of the success of combined gas turbines. Technical improvements such as material advancements and cooling innovations helped to increase gas and

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[68] It is unclear whether the other utilities do not consider enough value in GTI's R&D effort to justify funding it, or whether they enjoy being a "free rider." The latter interpretation assumes that some of GTI's research has spillover benefits extending beyond the funders.

[69] I want to thank Ron Edelstein for providing these statistics.

[70] Concentric Energy Advisors 2015, 38.

[71] GTI R&D funding is low compared to other utility-related, collaborative research entities. These organizations are management organizations and represent research arms of their respective industries. *See* Concentric Energy Advisors 2014, 39; and Edelstein, November 2015, 9.

combined cycle turbine efficiency, making them competitive in the power generation market.[72] Other innovations in the natural gas sector are numerous and will continue to be in demand to exploit the benefits that natural gas can offer the country.[73]

B. AGF study

The American Gas Foundation (AGF) study[74] starkly pointed out that the phasing out of the GRI funding has significantly reduced the natural gas industry's level of R&D spending, with GRI funding falling from a high of over $200 million to zero over a 10-year period.[75] The elimination of both the GRI and DOE programs resulted in a 50 percent drop in industry R&D funding in just three years. Industry R&D spending levels (and R&D staffs) dropped significantly during the late 1980s and early 1990s.[76]

The AGF study alluded to the importance of regulatory treatment of both the benefits and expenditures of R&D, for how much the natural gas industry is willing to spend on R&D. Regulatory actions affect how utilities recover their R&D expenditures, as well as the distribution of the benefits from innovation spawned by R&D between utilities and their customers.

The study mentions that the natural gas industry carries out mostly applied research and development. This is consistent with our earlier discussion on the private sector finding basic research most of the time too risky relative to the expected returns. Especially for regulated companies, as discussed later, customers tend to benefit more than the company from successes.

The AGF study as well as others has warned of the consequences of inadequate investments in R&D, including the negative effects on the safe, reliable, and cost-effective delivery

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72 Other contributors to gas turbine success were fuel availability, restructuring of the electric utility industry, and environmental concerns.

73 Examples include: (a) Fuel cells powered by natural gas, (b) 3-D and 4-D seismic mapping, (c) application of GPS technology, (d) methane detection and measurement, (e) gas sensing and monitoring, (f) natural gas vehicles (e.g., need for more cost-effective fueling stations, hybrid vehicles and home fueling) and (g) micro CHP for home use (e.g., need for a major breakthrough to become economical). *See*, for example, Edelstein 2015; and Johnson 2015.

74 American Gas Foundation 2007.

75 GRI funds included supply and utilization along with transmission and distribution.

76 Funding was reduced in the early 1990s due to pipeline competitive concerns. GRI was reorganized to accommodate the lower funding levels and to emphasize the near-term industry impact (applied research). The gap between historical funding levels and today's industry R&D budgets is much greater when factoring in the effects of inflation.

of natural gas to residential and business consumers.[77] Judging the adequacy of energy R&D priorities and expenditure, as pointed out later, is a difficult task.

C. MIT gas study

The MIT study on natural gas devotes a chapter to R&D.[78] It first identifies the benefits of R&D in five areas: (1) Reliability, (2) safety, (3) operational efficiency, (4) demand-side efficiency, and (5) the environment. The study highlights the combination of DOE funding, starting in the late 1980s, industry-matched GRI applied R&D and government incentives contributing to the commercialization of shale gas.

The study points out that, relative to the role of natural gas in the energy sector, DOE, the lead government funder of energy R&D, has historically spent little on projects related to natural gas exploration, production, transportation and use. During 1978-2010, for example, total DOE research funding for natural gas was just over $1 billion, or about $31 million per year. From FY 2008 to FY 2012, DOE R&D funding for gas technologies fell sharply from $70 million to $10 million.[79] Overall, DOE has given a low priority to natural gas R&D.[80]

The study emphasizes the importance of the FERC-mandated surcharge on interstate pipeline gas volumes in funding consumer-focused R&D for the natural gas industry. Funding levels were greater than $200 million/year for a number of years, with a total of over $3 billion during the life of the surcharge.

As the study notes, the abolition of the mandated surcharge was not offset by increased federal spending on R&D. The total R&D funding for natural gas is "down substantially from its peak and is more limited in scope."

The study remarks that the old R&D regime had positive attributes contributing to its success:

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[77] The R&D intensity for all gas transmission and distribution (T&D) collaborative R&D at 0.04 is less than half of the electric industry collaborative R&D for transmission and distribution (through EPRI) at 0.10 percent. [American Gas Foundation 2007, 50.] Other industries, such as propane, oil and water, spend more R&D dollars per customer than the natural gas industry. Some of them, such as water and electricity, conduct basic research "oriented at longer-term industry goals through their primary industry R&D collaborative and their government funding agencies." [Ibid.,1.]

[78] MIT Energy Initiative 2011, Chapter 8.

[79] One notable cutback was the elimination of the National Energy Technology Lab that focused on pipeline-reliability R&D.

[80] The American Gas Foundation study came to the same conclusion.

> The GRI and the RTF [Royalty Trust Fund[81]] research models highlight the value of federally-sanctioned alternative research models, with industry-led portfolios and dedicated multi-year funding mechanisms, in those cases specifically for natural gas RD&D. This value is derived primarily from: consistent funding over time; significant opportunities for industry input in program development and technical project reviews; and active collaboration between government, industry, academic institutions, the national labs and non-governmental organizations.[82]

Prospectively, the study identifies the need for more aggressive R&D activities by both government and the natural gas industry to accommodate the increased role that natural gas will play in the future:

> Clearly, the increasingly prominent role of natural gas in the energy mix creates an impetus for increased private sector RD&D, when the benefits of such activities can be readily appropriated…there will be a need for public and public-private funding of research with longer and/or more uncertain payback periods than will attract private funding. In addition, there are important research needs for natural gas transportation and end-use in addition to production[83]…The Administration and Congress should support RD&D focused on environmentally responsible, domestic natural gas supply. This should entail both a renewed DOE program, weighted towards basic research, and a complementary industry-led program, weighted towards applied RD&D, that is funded through an assured funding stream tied to energy production, delivery and use. In particular, the RTF should be continued and increased in its allocation commensurate with the promise and challenges of unconventional natural gas. Furthermore, consideration should be given to restoring such a public-private RD&D research model for natural gas transportation and end-uses as well.[84]

D. DOE's Gas Modernization Initiative and Quadrennial Energy Review

After the White House and the Department of Energy Capstone Methane Stakeholder Roundtable in July 2014, DOE announced a number of actions to help modernize the natural gas transmission and distribution systems and reduce methane emissions. As stated by DOE, these actions include "common-sense standards, smart investments, and innovative research." For example, DOE has launched a collaborative effort with industry to establish an Advanced Natural Gas System Manufacturing R&D initiative. The initiative will evaluate and scope high-impact manufacturing R&D to improve natural gas system efficiency and reduce leaks. DOE

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[81] The Energy Policy Act of 2005 established the Royalty Trust Fund to support a 10-year $500 million research program. The fund focused on exploration and production, including the associated environmental effects. Ibid., 167.

[82] Ibid., 168.

[83] Ibid., 160.

[84] Ibid., 169.

also proposes establishment of a new natural gas infrastructure technology program, focusing on R&D to improve pipeline and distribution system operational efficiency and reduce methane emissions.

DOE has also embarked on a *Quadrennial Energy Review* (QER)[85], among other things, to address the question: What are "mid- and downstream" methane reduction opportunities? It evaluates methane-emissions abatement opportunities. As stated in the *QER*:

> Addressing leakage and venting of methane—a powerful GHG—requires a range of additional actions, including prudent regulation; research, development, and demonstration; and public-private partnerships to reduce methane emissions, promote efficiency, and improve safety.[86]

VI. The Effect of Public Utility Regulation

A. Cost recovery and distribution of benefits

Public utility regulation plays a critical role in stimulating R&D by energy utilities.[87] Various features of public utility regulation affect how much and how utilities conduct R&D. For example, it affects the pace at which utilities innovate, the types of innovations they develop and adopt, and the management of R&D projects. The economics literature has devoted relatively little attention to regulated utilities' incentive to conduct R&D and innovate.

Incentives for utilities to invest in R&D depend on two broad factors influenced by public utility regulation.[88] One factor is regulatory lag; if a utility, for example, retains for a longer period the benefits from a cost-reducing technology, it would have more incentive to invest in the technology. Regulatory lag highlights the conflict between strengthening the incentive for innovation and allocating the benefits to utility customers in the short term. Bailey (1974) observed that regulatory lag is crucial to the incentive for innovation. If regulators respond immediately to

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[85] U.S. Department of Energy 2015. The QER is a comprehensive blueprint, as described by DOE, for meeting this century's energy challenges. Among other things, it includes policy recommendations and analysis on the environmental benefits of infrastructure investments that reduce natural-gas system leakage.

[86] Ibid., 7-3.

[87] Although environmental and other types of regulation affect R&D by utilities, this section focuses on public utility regulation.

[88] The presumption is that a linkage occurs between a utility's incentive to innovate and to conduct R&D. If, for example, a utility has a greater incentive for innovative energy-efficiency initiatives, it would tend to spend more on R&D related to those initiatives. In the extreme case where a utility has no incentive to innovate, it would have no reason to spend on R&D. As mentioned earlier, the demand for R&D is a derived demand for innovative activities that stand to improve the financial health of the company.

technological changes that reduce utility costs, for example, by lowering price proportionally, the utility realizes no benefit. Bailey showed that longer regulatory lag could enhance the incentive for utilities to reduce costs through innovation, although it delays the benefits to consumers.[89]

Another factor affecting utility incentives for innovation is cost recovery: When a utility is able to recover its costs for a new technology more quickly and with higher certainty, it will more likely adopt the technology. There are four aspects of cost recovery (e.g., rate-basing capital expense): Timing of recovery, method of recovery, criteria for recovery, and the accounting treatment of costs. Each of these affects the willingness of utilities to innovate.

Overall, regulation plays an important role in affecting the overall level of R&D spending. It determines whether any of the cost savings, improved operating performance and reduced capital requirements, for example, benefits only the utility, customers, or both. The regulatory treatment of R&D expenditures as investments in improvement of long-term utility performance is a critical determinant of industry R&D spending.[90]

B. Weak incentives for innovation

The standard narrative, buttressed by observation, is that regulation causes utilities to be cautious about innovating and taking risks.[91] Utilities are acting in the interest of their shareholders when they give low priority to technological change and other innovations. After all, if a utility has a choice of two technologies, one conventional and the other new, that have the same expected rate of return, it will tend to favor the conventional technology since it has lower risk. History has shown that utilities are often accepting of new technologies, if only because they increase their profits or mandates require them to.[92] Stronger regulatory incentives, however, could better align utilities' interest with customers'.

Traditional regulation tends to socialize both the benefits and costs of innovations, or worse. Whereas regulation may reduce downside risk, it also tends to eliminate gains from successful R&D, unless regulatory lag is substantial. If the utility hits a "home run" with R&D,

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[89] A similar analysis applies to patent life, which also allows greater benefits to an innovator as the patent lasts longer. Because of its relatively short duration, regulatory lag creates incentives for inexpensive innovations with short payback periods, but generally gives little incentive for major innovations with high up-front costs, which will only pay for themselves over a long period of time. The tradeoff between static and dynamic efficiency is at the core of patent law; that is, a lowering of price efficiency for higher productive efficiency. Because knowledge is cheap to transmit and hard to keep secret in the absence of patent protection, too little research and development would be undertaken. While patents induce more R&D, they do so at the cost of creating (temporary) monopolies.

[90] *See*, for example, Berg 1985.

[91] The weak incentives not only affect utilities' unwillingness to adopt known innovations that would improve their performance but also their search for innovations yet to be discovered. The last point is discussed in Weisman and Pfeifenberger 2003.

[92] *See*, for example, Burness et al. 1980; Harunuzzaman et al. 1994; and Joskow 1987.

for example, the benefits generally will go mainly to customers. Without some regulatory lag, a utility's reward structure would appear to be asymmetrical: A poor decision (ex post) is punished, but a good decision (e.g., one that reduces costs) is not rewarded.

Two major issues facing regulators are: (1) incentives for R&D by utilities and (2) incentives for R&D by potential entrants, vendors and manufacturers. Incentives for non-utilities are critical, as much of the new technologies that will benefit utility customers in the future will originate from entities that require connection to the utility's distribution systems and to customers directly.[93] Regulators' task is to ensure that these entities have access to the utility space.[94] Regulators will especially need to be vigilant about giving this access when a particular technology has the potential to erode a utility's monopoly status.

C. Changing the risk-reward relationship

The risk/reward relationship is critical for motivating utilities to innovate and undertake R&D activities. The common perception is that traditional regulation provides an unfavorable relationship for utilities to innovate or deploy new technologies. Broad ways to overcome this condition include: (1) Allow utilities to profit from new technologies, (2) avoid unduly discouraging utilities from conducting pilot programs and other R&D activities, and (3) eliminate any second-guessing of utilities' activities on R&D previously approved by regulators. In not discouraging pilot programs, for example, regulators could allow utilities to recover the costs, assuming proper management of the programs and adherence to upfront guidelines.

Does utility regulation need tweaking or major reforms to stimulate more R&D and innovative activity? Basically, regulators should consider giving utilities stronger incentives to innovate than what they have currently. A favorable environment for innovations would mean risk for utilities commensurate with the opportunity to benefit from successes, say, for five years or more. Such an environment existed in the 1960s, when both regulatory risks and bounds on earnings were largely irrelevant.[95] Utilities have often been adopters of new technologies when the conditions were ripe: Low risk and multi-year benefits.[96]

One extreme condition discouraging innovation is to "socialize the benefits and privatize the costs." Obviously a utility's nightmare is when it retains no benefits from an innovation but bears all the risks. This scenario is not only unfair to the utility but also creates incentives to

[93] New markets entrants across industries tend to favor radical innovations (e.g., disruptive technologies) over more incremental innovations, relative to incumbents. One reason is that they have more to gain than incumbents from successful innovations; for example, they might be able to erode the market dominance of the incumbent with a new product that catches the attention of consumers.

[94] By erecting unreasonable barriers, nonutility entities will have less incentive to innovate and conduct R&D that could ultimately benefit utility customers.

[95] *See*, for example, Burness et al. 1980; and Harunuzzaman et al. 1994.

[96] Exceptions include innovations that advance energy efficiency and public benefits, for which utilities would tend to inherently disfavor, under traditional price regulation.

resist innovation. A utility unable to recover any benefit from a new technology is unlikely to spend capital on that technology unless specifically mandated to do so.

The opposite situation is to "privatize the benefits and socialize the risks."[97] Here the utility retains all the benefits but bears none of the risks. This scenario would tend to motivate utilities to overspend on innovation and would undoubtedly be unfair to the customers who bear the risks. This scenario would meet with protest from utility customers, and rightfully so. Transferring too much risk to customers also creates a "moral hazard" situation in which the utility has little incentive to perform well because its risks have been transferred to customers.

Regulation can affect incentives for an external firm (or third party) to supply a cost-reducing invention or other innovations. It can do so through ratemaking, entry rules and other actions. The regulator's task of approving rates and rate designs is essential, for example, in engendering an efficient and socially desirable DG market. Ratemaking affects the utility's willingness to accommodate or foster DG, the economics of third-party DG investments, and the welfare of full-requirements customers.[98] Rates can therefore affect both the cost and benefit side of emerging technologies such as DG. As of now, ratemaking in many jurisdictions is in a state of disequilibrium, where regulators in several states are revisiting existing rate mechanisms because of discontent by major stakeholders.[99]

D. The net effect of utility regulation

The net effect of utility regulation on R&D/innovation is difficult to answer. As Table 3 shows, regulation has a wide umbrella with both positive and negative effects. Some of the negative effects may not pose a problem, since they may overall serve the objectives of regulation. One example is prudence tests that aim to protect utility customers from imprudent and uneconomical utility actions such as excessive utility risk-taking and poor investment choices.[100] Another reasonable limit on innovation would prevent a utility from assigning costs to all customers for an innovation that benefits only some customers.[101] Regulators should

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[97] For example, in 2008 the U.S. government offered bail-outs to banks, but the banks were allowed to retain all of their profits during good times.

[98] Ratemaking generally has implications for the ability of utilities to recover their costs, allocate costs between customer groups and achieve predetermined regulatory/public policy objectives. These objectives include the financial viability of utilities, the efficient use of electricity and the accelerated penetration of socially desirable new and emerging technologies.

[99] For example, many utilities are asking their regulators to review net energy metering rules. They argue that these rules are unduly favoring rooftop solar PV customers at the expense of full-requirements customers.

[100] One example is retrospective reviews, which penalize utilities for imprudent decisions and actions that otherwise would unduly burden customers with higher rates.

[101] By assigning costs to more customers, the cost per customer would be smaller. The utility's request for an innovation would be less contested and more likely to get regulatory approval.

ensure that utilities treat customers fairly, for example, by requiring funding for new technologies only from customers who expect to benefit. Some utilities may consider risk shifting to their shareholders as excessive when in fact it can reflect a fair and appropriate regulatory response to correct an imbalance in utility incentives or one-sided risk sharing.

Table 3: Features of Utility Regulation Affecting R&D/Innovation

Feature of Regulation	Effect on R&D/Innovation
Entry restrictions for new companies	▪ Reduces competitive pressure on utility to undertake R&D and innovate ▪ Natural monopoly structure favors large-scale technologies
Regulatory lag	▪ As to costs, deters innovation because it takes longer for utility to recover its costs ▪ As to benefits, encourages R&D/innovation because utility can retain benefits longer
Cost-of-service rates	▪ Diminishes utility's benefits from R&D/innovation ▪ Diminishes customer incentive to adopt certain technologies (e.g., storage benefiting from time-variant pricing)
Benefits allocated largely to customers	▪ Diminishes utility incentive to undertake R&D and innovate
Risk allocated largely to customers	▪ Increases utility willingness to undertake R&D and innovate ▪ Unfair to customers if utility captures most of the benefits ▪ Creates "moral hazard" condition for utility (i.e., excessive risk taking)
Same ratemaking treatment of conventional and new technologies	▪ Utility finds conventional technologies more attractive (i.e., the less risky technology)
Book depreciation	▪ Can diminish incentive to undertake R&D and innovate ▪ Can jeopardize utility's ability to recover fully the costs of existing assets
Prudence and "used and useful" tests	▪ Can deter utility from investing in high-risk innovations ▪ Can discourage utility pilot programs ▪ Protects customer against subpar utility management performance or unexpected outcomes
Emphasis on reliability and safety	▪ Shifts interest away from cost-saving innovations
Favoritism toward certain technologies	▪ "Jump starts" potentially socially desirable technologies ▪ Risks choosing the wrong technology

On net, though, it seems that utilities under-invest in R&D/innovation. First, most serious, the payoff to utilities may simply be too low relative to the risks. Second, utilities, as well as other for-profit companies, tend to discount or ignore completely public benefits. Third, traditional utility regulation (1) restricts the threat of competitive entry and (2) tightly controls a utility's prices and profits. For example, prices are based on a utility's actual costs. A fourth reason is that innovation can lead to the erosion of a utility's monopoly status.[102] One example is the development of combine cycle gas turbines that unraveled utility monopolies on electric generation.[103] A fifth reason is book depreciation causing "stranded costs" of old assets, which utilities may have to write-off.[104] Overall, the conventional wisdom is that regulation causes utilities to be slow to innovate, since the costs and benefits of innovation tend to be uncertain. An analyst expressed the situation this way:

> Regulated monopolies need not fear the loss of their monopoly and (to some degree) face legal profit constraints. They largely lack the motives for investing in R&D in the Schumpeterian world. Alternatively, regulated firms face regulatory oversight. R&D programs by regulated firms are molded to respond to incentives structured by political as well as economic imperatives.[105]

The inherently high risk of R&D/new technologies has implications for both utilities and regulators. One is that they should discount the benefits to account for the more-than-remote probability of disappointing benefits. Regulators may also want to allow a higher rate of return for those investments that turn out to be successful. Uncertainty of outcomes also means that both utilities and regulators should resist the temptation to place all of their bets on a single technology, even though current information may support such a position. Experience has shown that projects can become white elephants or fail miserably. Decisions made under uncertainty can easily lead to regrettable outcomes.

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[102] Innovation is not outside the control of utilities since they can influence the innovative activity of potential entrants. Utilities can erect an entry-deterrent strategy toward innovations that threaten their monopoly status. Although a utility has monopoly power, there may be competition in R&D among vendors, manufacturers and third-party providers to serve retail customers. Innovations producing substitutes to utility services can reduce scale economies, making entry feasible, and increase demand elasticities, thus eroding the market power of the utility.

[103] Rooftop solar PV may have a similar effect at the distribution level, although the jury is still out on whether it will.

[104] Regulators can learn from the experience of the telecommunications in the 1980s: When companies deployed new technologies, state utility regulators allowed them to recover their prior investment (via accelerated depreciation) and deploy the new technologies.

[105] Cohen and Sanyal 2008, 3.

E. Regulatory tools

Regulators have access to a number of tools to bolster R&D/innovation. As a cardinal rule, any utility will find innovation financially attractive when it expects profits to compensate it for the risk it bears. One guide is to change the risk-reward relationship by aligning rewards with utility risks.

Although the net effect of regulation on R&D/innovation is difficult to determine, the consensus seems to lean toward the negative. The conditions required for non-regulated firms to innovate seem to be lacking for utilities. For example, why should a utility make an added effort to innovate when most of the benefits will go to customers or society?

The major regulatory tools to bolster R&D/innovations are the following:

(1) Variations of ROR regulation such as economic depreciation[106] and risk-adjusted returns[107]

(2) Price caps[108]

(3) Focused incentives (e.g., financial reward for successful innovations)[109]

(4) Profit or benefit sharing (e.g., the utility retains the benefits of a new technology for 5 years)

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[106] *Economic depreciation* = d - i + a, where d = wear-and-tear or physical depreciation rate (e.g., number of units of output from a machine declining at a rate "d" over time), i = inflation rate, and a = technological change. Under traditional ROR regulation, utilities lack incentive to retire old capital and replace it with new capital incorporating the latest technology. They are susceptible to stranded costs when the allowed depreciation rate is below economic depreciation. The reason is that ROR regulation under-depreciates certain assets by ignoring technological progress.

[107] For example, regulators can allow higher returns for investments, like new technologies, with higher risks.

[108] In its purest form, a price-cap regulatory system regulates a utility's prices but not its profits. Price caps generally allow utilities to earn higher profits. Compared to ROR regulation, a price-cap plan also imposes higher risk on the utility. The focus shifts from "inputs" to "output," which in theory should improve the utility's interest in deploying innovation to serve customers.

Price cap regulation typically permits revenues to diverge from realized costs for a specified period of time (e.g., four years), but does not promise specific long-term returns on investment. Although such a scheme can provide strong incentive for short-term innovation and cost reduction, it may provide limited incentive for long-term infrastructure investment. The choice between ROR regulation and price cap regulation will therefore depend in part on the type of investment being considered.

[109] Incentive-based regulation puts some risk on the utility, but it also allows the utility to benefit from "successful" outcomes. Designing a properly structured incentive mechanism is challenging but important to avoid distortive outcomes. *See*, for example, McDermott et al. 1992. The authors make the observation that "an incentive may be necessary to encourage adoption of a new technology at the same time another incentive is needed to maintain cost control of the innovative project." [at 27]

(5) Regulatory lag[110]

(6) Limited retrospective reviews[111]

(7) Planning (prospective) process[112]

(8) Regulatory commitment[113]

(9) Explicit rules (e.g., a utility should recover all prudent costs for an R&D project even if it is unsuccessful[114])[115]

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[110] As mentioned earlier, the effect of regulatory lag is similar to that of patents, by allowing the company to retain the benefits from innovation over some reasonably long period. It is defined as the delay between an event that changes a utility's costs or revenues and the utility's subsequent change to its rates. Regulatory lag has a mixed effect on utilities' willingness to innovate: On the one hand, lengthening the time allotted for utilities to recover their costs increases their financial risk; on the other hand, lengthening the time allotted for utilities to retain the benefits improves their financial condition. ROR regulation, like "cost-plus" contracts and other similar transactions, typically provides limited incentive for innovation and cost control.

[111] Retrospective reviews have probably caused utilities to favor low-risk investments, especially if their opportunities to earn high profits are constrained. Limited retrospective reviews mean scrutinizing the prudence of utility decisions leading up to an outcome but no second-guessing based on outcomes alone.

[112] Regulators might consider, for example, evaluating new technologies in the context of integrated resource planning (IRP). Several states require both electric and gas utilities periodically to submit integrated resource plans. As a prospective review, IRP allows the regulator and non-utility shareholders to compare new technologies, before the utility commits to them, with other options on a so-called "level playing field." IRP has particularly bolstered energy efficiency and DG because it requires utilities to review, on an equal basis, these options along with traditional supply-side technologies.

[113] Regulatory commitment can be full, partial or none. Partial may involve, for example, the regulator pre-approving a project. Any imprudence in utility decision-making affecting completion of the project is still subject to disallowance. Completely eliminating the risk to utility shareholders would tend to overly blunt utilities' incentive to contain the costs of "innovation" projects and carefully evaluate their economics. In general, regulators satisfy their duty to protect customers from excessive costs through substantial oversight of "innovation" programs and the traditional regulatory prerogative to examine a utility's books and management and potentially disallow imprudently incurred costs.

The U.K.'s approach under its "innovation" stimulus program requires shareholders to initially bear a portion of project costs, with refunds based on meeting predefined success criteria. Italy also has incentive-based regulation by offering higher returns on invested capital for competitively selected "innovation" projects.

[114] For example, regulators should require utilities to assume reasonable risks, but encourage them to innovate by allowing them to pass at least some costs of failures on to their customers.

[115] A rule could allow, for example, utility investments in electric-vehicle recharging stations, on the basis of market failure; that is, the private sector, for whatever reasons, would under-invest in recharging stations. Utilities could help stimulate electric vehicles by expediting permitting and

(10) Policy guidance (e.g., guidelines on pilot programs; commission policy on utility R&D and innovation)[116]

F. Major regulatory matters

Regulators should consider addressing several questions on utility-funded R&D. They include the following:[117]

(1) Why should a utility undertake a risky endeavor when the payoff is small? Private companies spend on R&D only when success brings a high payoff. In the regulated environment, unless regulators force utilities to adopt a certain technology, a rational utility would devote little effort to R&D. Since most R&D efforts end up in failure, a utility risks not recovering costs for the majority of projects if the regulator, for example, applies a "used and useful" standard.

(2) What incentives do utilities have to innovate? What drives the demand for utilities to innovate?

(3) What is the effect of a new business model on creating new demand for innovation by utilities, customers and third-parties?[118]

(4) How can regulation eliminate artificial barriers to R&D/innovation?[119] What are those barriers? How can regulation create a level playing field between new technologies and old technologies?

(5) What is the role of R&D in innovation? That is, what is the link between R&D and innovation?

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installation, in addition to offering time-of-use rates for electric-vehicle charging. The market-failure argument would seem to hold less for the DG market, which has attracted a large number of vendors, installers and other non-utility providers.

[116] One study (Concentric Energy Advisors 2014, 1) identifies what seems like a reasonable policy statement: "Utility regulators should provide crucial guidance and oversight and establish evaluation criteria (e.g., clear standards) that include customer benefits from innovative investments."

[117] The Appendix contains additional questions that regulators can ask about utility-funded R&D.

[118] A new business model can itself be an innovation.

[119] An artificial barrier, by definition, would cause a utility not to seek and develop socially desirable innovations. It can arise from market or regulatory failures such as flawed prices for utility services. As an illustration, electricity prices that fail to fully reflect the environmental costs of production could be an undue barrier to investment in clean-energy technologies. Similarly, if retail electricity prices are below marginal costs, that could be a barrier to optimal investment in energy-efficiency technologies. Also, an asymmetric risk/reward relationship can discourage a utility from making socially beneficial investments in a new technology. Regulators should try to mitigate these barriers whenever cost-beneficial.

(6) Which entities can and should carry out innovation? Why should utilities get involved with the development of new technologies? Can other entities serve this role more effectively and efficiently?[120]

(7) What is the demand for innovation by utility customers? How is this revealed?

(8) What are the regulatory objectives for R&D?[121]

(9) What are the benefits of collaborative research?

(10) What actions can regulators take in accommodating and supporting innovation that is in the public interest?[122]

(11) What distinct actions involving R&D should fall under regulatory purview?[123]

(12) Should regulators establish guidelines or principles on utility R&D?

(13) How should regulators evaluate R&D projects, ex post and ex ante?[124]

Because of the concern that utilities may underinvest in R&D and innovation, regulators should consider taking a proactive role.[125] At the minimum, they should keep abreast of emerging technologies and require utilities to evaluate them for their feasibility and economics. Regulators may have to push utilities toward innovative activities for which utilities lack incentive. A posture of supporting only utility preferences for certain new innovations falls short of serving the public interest. On the other hand, mandating that utilities adopt certain new innovations may enter the realm of micromanagement, which has its own drawbacks.[126]

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[120] The value of new technologies depends on user management (e.g., creativity of eventual users of a new technology) besides the inventor's actions.

[121] One objective would be to improve the long-term performance of utilities.

[122] Regulators might endorse, for example, a utility business model that supports R&D by utilities, third-party service providers, and outside vendors and manufacturers.

[123] The major actions are (a) the selection of projects as part of a portfolio, (b) funding levels, (c) funding sources (taxpayers, utility ratepayers, utility shareholders, third parties) and (d) project management. Although the risks associated with individual projects may be high, for example, the risk of the overall portfolio may be reasonable and more tolerable. A single portfolio may have one objective, like clean air or energy efficiency or grid modernization. Individual projects can compete with each other for commercial viability.

[124] For credibility, regulators should require evaluation of R&D projects funded by utility customers. This begs the question of how they should evaluate them. Calculating the benefits, for example, would be especially challenging. One possible criterion is the likelihood that a project will eventually have commercial value. Utilities themselves should document their investments and returns to demonstrate the benefits to customers from their aggregate R&D efforts.

[125] *See* the earlier discussion.

[126] One major problem is premature selection of winners in an environment of high uncertainty.

G. Regulatory principles

1. Examples of principles

Regulators can apply a set of principles for R&D, just like they can for utility ratemaking and planning. Principles have the benefit of providing utilities with more certainty over what regulators expect of them in undertaking R&D. Regulators would have to decide whether R&D is an important enough utility activity to establish principles. The suggested principles below derive from studies and just common sense.

(1) Sustained and stable funding that avoids fluctuations because of political and other factors[127]

(2) Matching of funders and beneficiaries (e.g., taxpayers funding R&D with public benefits)

(3) Funding levels sufficient for achieving regulatory/policy goals[128]

(4) A portfolio approach for selecting projects within broad programs, because of inherent uncertainty and multiple policy/company objectives[129]

(5) Reasonable risks assumed by utilities and pass through of prudent costs from failed projects to customers[130]

(6) Alignment of expected rewards and risk (e.g., higher-risk R&D should have a higher expected return)

(7) Avoidance of choosing winners, which can easily lead to unfavorable technology lock-in (e.g., placing all R&D expenditures on a single technology)[131]

(8) Appropriate role of utilities in different stages of R&D and accommodating third-parties[132]

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[127] Features of bad R&D include ad hoc, temporary projects that overlap with other projects, and with little measurement and evaluation of the net benefits.

[128] Small investments in R&D generally do not yield cost-beneficial results. The size of the company therefore determines whether it has the critical mass to succeed at a research project.

[129] Individual projects are more likely to fail than succeed. Innovation outcomes without exception are uncertain. This helps explain the dubious wisdom around public policies trying to pick technological winners ex ante. Policies should support a wide range of technologies.

[130] The assumption is that undertaking the project was prudent but the results turned out to be disappointing. For R&D, such an outcome would not be uncommon and, in most instances, it probably would not reflect poorly on the utility. Certainly, when a utility acts imprudently it should bear the costs of subpar outcomes. On the other hand, a project's failure can provide useful information, justifying cost recovery.

[131] Past efforts by the government in picking winners and then abandoning them include R&D efforts for fast breeder reactors and fuel-cell cars using hydrogen.

(9) Articulation of criteria for R&D: For example, FERC has the following criteria, "R&D projects should be well-defined, clearly explained and with consumer benefits, targets and justification"[133]

(10) Selection of utility-customer-funded projects based on the expected benefit-to-cost ratio to them[134]

(11) Minimal overlap of research conducted by other entities[135]

(12) Well-managed R&D projects[136]

(13) Measurable outcomes (e.g., actual benefits to customers)

(14) Retrospective and prospective analyses[137]

A long-term commitment to a new technology beginning with basic research is probably the most important lesson learned from decades of experience. As noted in one study,

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[132] Should utilities, for example, undertake only development and demonstration? How can utilities accommodate R&D/innovations created by third parties?

[133] U.S. Federal Energy Regulatory Commission 1998, C-1. FERC has also stated that R&D should benefit gas consumers within a reasonable period of time, and be confined to basic research, applied research or technology development. FERC struggled with determining what part of commercial scale (i.e., demonstration) plant is R&D and what part is a normal business investment.

[134] A project with a higher benefit-to-cost ratio means that for every dollar funded by utility customers the expected benefits are greater.

[135] In other words, research should complement other efforts.

[136] The literature finds that the methods and practices in managing R&D are critical to obtaining maximum benefits. A sponsor of a recently completed analysis of R&D spending in U.S. industry concludes: "Successful innovation demands careful coordination and orchestration both internally and externally. *How you spend is far more important than how much you spend."* [Amble 2005.] [Emphasis added] R&D benefits are more likely when projects are managed effectively and are focused on achieving societal or private needs. R&D should be planned and managed properly to maximize the return on investment.

[137] There is a need for detailed, thorough and independent assessments of R&D projects and programs. *Retrospective analysis* looks at the actual results to determine whether or not an R&D program was performed as planned. *Prospective analysis* evaluates whether an R&D program has the potential to produce benefits that justify the costs. The former analysis can help to determine whether an R&D program should continue while the latter analysis addresses whether an R&D program should even begin.

As a principle, state utility regulators should fulfill their duty to protect utility customers from excessive R&D costs or misallocated costs through (a) oversight of innovative programs, (b) their traditional regulatory function of examining utility books and management and (c) potentially disallowing imprudently incurred costs. One problem is ratepayer-funded R&D activities that fall outside the long-term interest of customers.

> Any new technology is based on some basic scientific concept, and the process of its development into a new energy technology is long and complex. It can take decades for a technology to reach the stage when it is ready for market use. Hence, to be effective, a technology policy must be backed by a stable long-term commitment that corresponds with technology's long cycle.[138]

2. Rationale for a portfolio approach

As a rule, more diverse systems exhibit a higher degree of robustness in response to external shocks whether or not these shocks were previously assigned a probability distribution (i.e., subject to risk or ignorance). The economic perspective on diversity and robustness is succinctly captured by the adage "don't put all of your eggs in one basket." The notion of diversity and robustness comes up in many social contexts. For R&D, the economics can change quickly because of market events (e.g., both domestic and global) and new government policies. Efforts to further refine coal gasification, for example, might have been reasonable prior to the shale phenomenon, but certainly lesser so afterwards.

There are three major dimensions to a portfolio approach to R&D: (1) investments in different technologies, (2) investments in different stages of technology development and (3) different mechanisms for government (or GTI and EPRI) to interact with the private sector, non-profit entities and universities. Because some innovation efforts prove highly successful and others less so, regulators should take a portfolio approach to judging utilities' "innovation" performance, rather than weighing the outcomes of individual projects too heavily.[139]

Portfolio theory, originally developed for financial assets, offers several perspectives on the economics of diversity for physical assets such as R&D activities.[140] It says that the risk of a portfolio (i.e., "bundled assets") relates to: (1) the inherent risks of individual assets, (2) the share of individual assets in a portfolio, and (3) the covariance (i.e., the inverse of mutually disparity) between the different assets. The portfolio approach selects investments to reduce risk to some tolerable level by considering the likelihood of future events such as fuel-price shocks and stricter environmental regulations. Covariance measures the diversity of the portfolio, with a lower value reflecting greater diversity and lower overall portfolio risk, assuming other things held constant.

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[138] The study also remarked that, "Basic research projects are, on average, at least 20 years away from market. In the oil and gas sector, for example, the average lead time for a new technology from concept to market is roughly 16 years... Although individual projects are relatively inexpensive to fund, basic research requires a significant overall public commitment." [Khanberg 2012, 14.]

[139] A balanced portfolio includes varied investments in (a) different technologies, based on predetermined priorities and (b) different stages of the technology development process. *See* Anadon et al. 2011; and Krebs 2006.

[140] *See*, for example, Markowitz 1952.

H. The benefits of collaborative research

The dramatic drop in collaborative R&D by the natural gas utilities over the past 20 years is a real concern. Collaborative research has several benefits that regulators should recognize. They include:

- Avoids duplicative efforts and inefficiencies[141]
- Mitigates the "free rider" problem
- Exploits economies from pooling company resources to undertake R&D[142]
- Results in a more diversified portfolio of research projects[143]
- Allows companies that otherwise lack funds to participate in more R&D activities
- Spreads the costs of high-risk projects[144]
- Helps participants stay on top of the latest technology developments
- Overall, enhances the industry's capability to leverage R&D investments for addressing common needs

Collaborative research is more likely when companies are unconcerned about keeping a new technology or new information proprietary.[145] For example, collaborative R&D is stronger

[141] An acute problem, especially in non-regulated industries, is the duplication of R&D projects by competing companies. Excessive R&D expenditure can be an outcome.

[142] Companies need a critical minimum scale to reap benefits from research; very small companies tend therefore not to conduct R&D. Among the companies that choose to invest in R&D, larger companies have more resources at their disposal than their smaller counterparts and will thus invest more. Scale economies may require mergers or joint R&D activity.

EPRI, for example, estimates that by pooling resources of its members, it provides them with $10 in R&D for every one dollar received in contributions from an individual utility. Assume, for example, that 10 utilities each contribute $100,000 to EPRI for a particular project. Each utility is getting $1 million of research for only $100,000; that is, each utility without collaboration would have to spend $1 million to get the same R&D output.

[143] A single utility would likely have interest in a wider portfolio of R&D projects than what it can fund itself.

[144] As one reviewer commented, even though collaborative or cooperative R&D ventures help to spread risk, companies might fear the threat of antitrust violations.

[145] As mentioned earlier, collaborative research has dwindled considerably with restructuring, and increased competition, of the natural gas and electricity industries.

if companies do not compete with one another.[146] Collaborative R&D offers more advantages for industries that are regulated because of non-competitive conditions, such as the natural gas, water and electricity sectors.

State regulators might want to consider encouraging gas utilities to contribute more, say, to GTI and other collaborative efforts.[147] But in doing so, they should ensure that utility customers are getting value for the funds they provide to R&D projects. Regulatory oversight of collaborative research might cover how R&D management allocates customer-funded monies to different projects, the management approach applied to the projects, the evaluation of projects, and the potential benefits to customers.[148] Throwing money on R&D projects that are poorly managed and with dim prospects for success is something that regulators would want to discourage.

VII. Concluding Comments

This paper does not definitely answer the question of whether energy utilities are spending too little on R&D. After all, coming to such a conclusion would require more information than what this paper could provide. For example, it would require not only a complex technical assessment on an individual utility level, but also a number of value judgments about the social desirability of both private and public R&D initiatives. For the utility sector, a policymaker would need to know both (1) the *optimal level* and nature of research activities that promote the public good and (2) the *current status* of R&D activities in the sector; both factors are either unknown or highly speculative. It may well be true that some utilities are undertaking adequate R&D while others are not.

Looking across all utilities, however, based on the trends and other evidence, one could conjecture whether or not utilities are spending enough on R&D. Overall, the evidence suggests that speedier action on a larger scale would be in the public interest. Similar to other sectors of the economy, R&D in the utility sector is a public good that is likely to be suboptimal in scale without substantial public financial support. Compared to other regulated sectors, the natural gas industry has suffered draconian cutbacks in R&D since around 2000.

Regulators will need to exercise vigilance in making sure that utilities do not underinvest in R&D and innovation, which for the various reasons outlined in this paper, can happen. One reason is the possibility for a new technology to erode a utility's monopoly status. Overall, as one industry observer has remarked, utilities operate within a "culture of caution." As one

[146] Since companies in competitive industries pursue R&D to mostly expand their market and increase operating efficiencies, collaborative R&D options are less favorable.

[147] Most of the collaborative research done by GTI and EPRI emphasizes shorter-term product development rather than basic research and even much applied research.

[148] Organizations managing R&D, such as GTI and EPRI, should have good administrative skills, be technically competent, and perceived as objective in conducting R&D that is in the public interest.

interpretation, this culture encourages prudent use of tried-and-true operating practices and technologies.

Regulators should ensure utility customers that they are getting bang for their buck. Evaluation can also help enhance the future performance of R&D projects, for example, by learning from past failures (i.e., iterative improvements). Analysts have concluded that poor R&D programs often have a short-term time horizon and deficient resources dispersed over a number of uncoordinated projects that lack useful performance metrics related to outcomes. What we have learned across a wide array of experiences is that the decision process for allocating R&D funds across different programs is just as important, if not more so, than the level of R&D funding. Good planning and management help to maximize the return on R&D investment.

Alternative energy sources such as clean energy will remain cost-inferior to conventional sources unless technological breakthroughs emerge.[149] Even though certain new technologies have exhibited promise and seem to have bright futures, their wide penetration in the marketplace will depend on further refinements to lower their costs and improve their performance.[150] Major technological breakthroughs are a requisite for making the transition to low-carbon energy a reality as well as cost-effective. The U.S. and other countries will require further development of emerging technologies, for example, to advance the goals of global-warming policies, with some yet to emerge on the scene and others currently immature and still unable to be economically competitive without subsidies. In this environment, R&D has potentially large benefits.

Finally, the goal of this paper is to leave the reader with three thoughts. First, R&D plays a vital role in society that is often overlooked by policymakers. Second, the concern that the U.S. is spending too little on energy R&D seems very real. R&D is a hard sell to both the private sector and government, particularly as our society has become more myopic and less patient for benefits farther out than immediate or short term. Third, public utility regulation should consider providing utilities with stronger incentives to encourage innovation and R&D. One broad approach under the control of state utility regulators is to change the risk-reward relationship so that utilities have greater motivation to innovate. As the electric industry transforms, a potentially large benefit can come from utilities optimally integrating new technologies into their distribution system. This integration will likely require ingenuity and innovation, bolstered by robust regulatory incentives.

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[149] Mandates or incentives for reductions in carbon dioxide, for example, simultaneously create an incentive for utilities and other polluters to find ways to lower pollution at lower cost, including the adoption of new technologies.

[150] Diffusion of new technologies is normally a gradual, dynamic process, rather than a process where a new technology is adopted *en masse*: The process usually starts with few early adopters, followed by a more rapid period of adoption, and then by a more moderate adoption rate once most potential users have purchased the technology. Often times, a technology that appears to surpass competing technologies in performance and cost will not immediately be chosen over existing technologies. A key policy question is whether this slow diffusion is a result of rational actors responding to different incentives or a consequence of market inefficiencies and undue barriers.

Appendix: Questions for Utility Regulators on R&D

General

(1) What do we mean by "R&D"? How is it distinguishable from other utility investments?

(2) How important are R&D investments in improving utility performance and benefiting utility customers and society as a whole?

(3) What innovations, developed in the last 10-15 years, have benefited utility customers the most? What role did GTI and EPRI play in their development?

(4) What technologies and other innovations have the most promise as of today, but will require additional R&D to effectuate a breakthrough that would have a major effect on the gas and electric industries and their customers?

(5) How has industry restructuring in both the natural gas and electricity industries affected utilities' willingness to fund and conduct R&D activities?

(6) What role should utilities play in funding and conducting R&D?

(7) What roles should federal and state governments, non-utility energy providers, collaborative research entities, vendors, and manufacturers play?

(8) Past experience has shown that non-utilities have been a major contributor of innovations benefiting utility customers, created from their own R&D activities. Why then should we be concerned about utility R&D activities? What role do utilities have to diffuse innovations developed by third-party entities?

(9) Is the downward trend in utility-funded R&D a legitimate concern?

R&D performance

(1) How can the value of R&D be measured? Is it possible?

(2) What are the major challenges for regulators in evaluating and overseeing utility R&D investments?

(3) What information should regulators have to adequately evaluate the merits of an R&D investment? How should they treat the inherent uncertainties in the benefits and costs?

(4) What has been the track record of utilities investing in R&D over the years? What are the indicators? Have utility investments in R&D fluctuated over time? If so, why?

Regulatory policies and practices

(1) What can state utility regulators do to stimulate more R&D?

(2) What aspects of regulation have the most adverse effect on utility-funded R&D? How can regulators best mitigate them to stimulate more R&D?

(3) Should utility customers, rather than utility shareholders, fund R&D projects?

(4) What incentives do utilities have for R&D investments?

    (a) Do these incentives coincide with utilities' R&D investments that are in the interests of customers and society as a whole?

    (b) If not, why not, and what can regulators do to mitigate this problem?

    (c) Is the existing risk/reward relationship for most utilities symmetrical, meaning that it allows utilities an adequately high return on R&D investments to compensate them for risk?

    (d) If this relationship is not symmetrical, what should regulators do to make it so?

(5) What are the major regulatory barriers to utility investments in R&D? What should regulators do to address them?

(6) Should regulators give utilities special treatment for the recovery of costs associated with R&D?

(7) Should regulators have a special policy on utility R&D investments? For example, should they establish guidelines or general principles articulating acceptable R&D investments, or criteria for cost recovery?

(8) How can regulators hold utilities accountable for R&D investments while at the same time not discouraging them from such investments when in the public interest?

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