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Evaluating the Risks of Alternative Energy Policies: A Case Study of Industrial Energy Efficiency

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ABSTRACT

Numerous studies have shown the potential for U.S. manufacturing to cut its energy costs by installing more efficient equipment that offers competitive payback periods, but the realization of this potential is hindered by numerous obstacles. This paper evaluates seven federal policy options aimed at revitalizing U.S. manufacturing by improving its energy economics while also achieving environmental and energy reliability goals. Traditionally, policy analysts have examined the cost-effectiveness of energy policies using deterministic assumptions. When risk factors are introduced, they are typically examined using sensitivity analysis to focus on alternative assumptions about budgets, policy design, energy prices, and other such variables. In this paper we also explicitly model the stochastic nature of several key risk factors including future energy prices, damages from climate change, and the cost of criteria pollutants. Using these two approaches, each policy is "stress tested" to evaluate the likely range of private and social returns on investment. Overall we conclude that the societal cost-effectiveness of policies is generally more sensitive to alternative assumptions about damages from criteria pollutants and climate change compared with energy prices; however, risks also vary across policies based partly on the technologies they target. Future research needs to examine the macroeconomic consequences of the choice between a lethargic approach to energy waste and modernization in manufacturing versus a vigorous commitment to industrial energy productivity and innovation as characterized by the suite of policies described in this paper.

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1. Introduction

History has shown that the energy sector is highly vulnerable to unanticipated and unpredictable occurrences that undermine the ability to forecast the precise outcomes of energy policy initiatives. It has been suggested that U.S. industrial policy is uniquely capable of expanding U.S. employment opportunities while promoting a clean energy economy. Improving the energy efficiency of industry, in particular, is seen as essential for maintaining the viability of domestic manufacturing, especially in a world economy where production is shifting to low-cost, less regulated developing countries. Numerous studies have estimated a large potential for cost-effective energy-savings in U.S. manufacturing, but a variety of obstacles hinder the realization of this potential. This paper evaluates seven federal policy options aimed ultimately at reviving U.S. manufacturing by improving its energy economics while also achieving environmental and energy reliability goals.

The policy options that we evaluate are grounded in an understanding of industrial decision-making and the barriers impeding efficiency improvements (Brown and Sovacool, 2011). At the same time, our analysis recognizes that forecasting outcomes of energy policies must consider the unexpected. As a result, when we were asked to identify and evaluate federal policy options to motivate greater investment in energy-efficient manufacturing, we elected to conduct this assessment within the context of key uncertainties. Past research underscored the challenge of curbing industry's energy consumption and greenhouse gases (GHG) emissions while at the same time increasing global competitiveness. Well documented barriers to expanding investments in industrial energy efficiency in combination with unexpected "black swans" such as the recent global economic downturn help to explain the remaining existence of a large energy-efficiency gap in U.S. industry (CCCSTI 2009; Brown, Cortes, and Cox 2010).

This paper proceeds as follows: In Section 2, we discuss the process and criteria by which our policy options were selected, and present a short description of each option. In Section 3, we describe the structure of our policy analysis of the seven options, taking into account the private perspective including investment costs and energy cost savings, and the societal perspective including the direct cost of policy implementation and the benefits of reductions in CO_2 emissions and criteria pollutants. Section 4 describes the methods we used to include uncertainties in policy design, future energy prices, and the damage costs of criteria pollutants and CO_2 emissions. Section 5 presents the results, and our conclusions are discussed in Section 6.

2. Selection of Federal Energy Policy Options

To define the policy options for detailed analysis, the research team met with stakeholders from government, industry, and other relevant sectors, convened a workshop of experts, consulted the academic and industry literature, and examined legislative actions to provide insights into the political feasibility of alternative energy policies. Because the focus of this study is on methods for accelerating the deployment of existing energy-efficient technologies, we did not consider policy approaches focusing on improved technical performance or reduced implementation costs that might occur as the result of expanded R&D programs. Instead, we focused entirely on deployment policies.

Numerous policies were considered for detailed analysis, and these were reduced to a short list of seven policy options, by applying the following policy evaluation criteria.

- **Appropriateness of the Federal Role**. The policy must clearly define an appropriate federal role, one that does not pre-empt state or local action.
- **Broad Applicability**. Since the number of proposed policy options and measures to be analyzed is small, but the desired impact is large, those policy options selected for analysis should be broadly applicable.
- **Significant Potential Benefits**. Those options that produce large benefits should be favored over those producing fewer benefits.
- **Technology Readiness**. The policy options selected should address barriers and/or risks of mainly an institutional, policy, or non-technical nature.
- **Cost Effectiveness.** In selecting policies to study, consideration should be limited to those that would be expected to have reasonable costs, significant social benefits, and a relatively high benefit-to-cost ratio.
- **Administrative Feasibility**. Policies selected should be fairly easy to implement, manage, and enforce. Some may require training a large workforce for implementation, while others may be able to focus training on limited players within the delivery system. The latter is more desirable.
- **Potential for Rapid Implementation**. Preference should be given to policies that can deliver benefits rapidly.

These criteria were developed in consultation with the Department of Energy (DOE)'s Office of Policy and International Affairs, and in previous research that benefited from substantial peer review including two workshops with industrial and academic policy experts. Another application of these criteria can be found in an assessment of federal policy options for promoting greater energy efficiency in the housing market (Brown et al. 2011a).

Figure 1 shows the seven policy options that passed the screening based on these evaluation criteria. The figure reflects the fact that any new policy initiatives must be integrated into the landscape of policies and programs that are already in place (illustrated by the left-hand boxes). The numerous arrows and linkages in this figure highlight the portfolio nature of the seven policies, which can be classed in three groups – regulatory, information/training, and financing – as shown in the figure and described below.

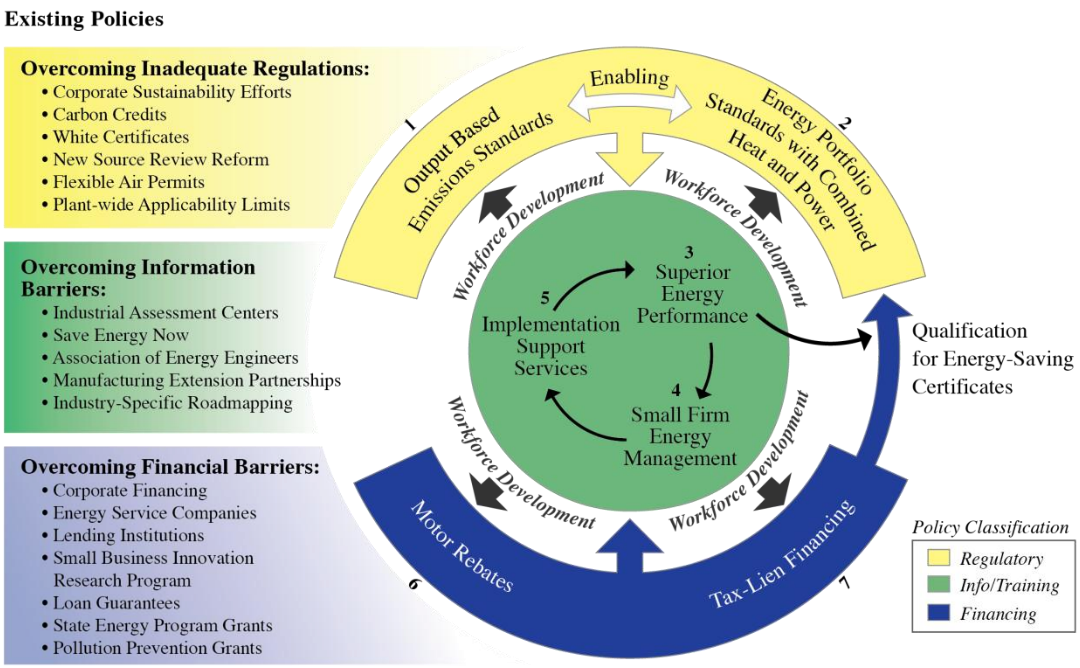

Fig. 1 Industrial Energy-Efficiency Policy Options

Two of these policy options address federal and state regulatory hurdles (shown in yellow in Figure 1) that limit the opportunities for firms to invest in efficiency. Both of these aim to increase energy-savings from combined heat and power (CHP) systems (sometimes referred to as "cogeneration"):

Output-Based Emissions Standards (OBES) would provide financial incentives and technical assistance to states to spur adoption of OBES – as authorized by the U.S. Environmental Protection Agency (USEPA) – to reduce energy consumption, emissions of criteria air pollutants and GHG, and regulatory burdens. An Output-Based Emissions Standard moves pollutant regulation from traditional metrics like parts-per-million, which can overlook the efficiency and total pollution of a system, to a different metric, such as tons/year, which is capable of incorporating such concerns (USEPA 2004). Several states have already implemented variants of these standards within their jurisdictions, and a national effort could lead to widespread cogeneration at factories and large facilities over the near and long term (Cox, Brown, and Jackson 2011). The United Kingdom has adopted an output-based Quality Assessment (QA) for CHP to incentivize its implementation, and the European Union has encouraged following that example. Output-based standards could capture the total efficiency of CHP and have spurred the adoption of CHP (Freedman and Watson 2003).

A **Federal Energy Portfolio Standard (EPS) with CHP** would mandate that all electric distributors meet an EPS, with CHP as an eligible resource. Often referred to as quotas or obligations in other countries, energy portfolio standards have been established as requirements in 29 U.S. states. In at least 14 of these, CHP or waste heat recovery is a qualifying resource (USEPA 2009). In addition to nationalizing the EPS requirement and including CHP eligibility, this policy would extend and increase (from 15% to 30%) the current investment tax credit for

CHP. Concurrently, this policy would establish measurement and verification methods for qualifying CHP resources and encourage a national market for trading energy-efficiency credits. Without strong financial incentives, the uncertainties, lack of familiarity, and other adoption barriers would remain strong deterrents to the installation of new CHP systems. Similar types of quotas and financial subsidies are boosting the implementation of CHP in other industrialized nations. For example, Denmark, Belgium and the Netherlands have strong subsidies and tax exemptions to ensure that CHP installations can flourish (European Association for the Promotion of Cogeneration 2001).

Three of the policy options would help fill information gaps and workforce training needs in industry (green in Figure 1), targeting large, medium, and small firms:

Incentives to promote the adoption of the **Superior Energy Performance (SEP)** program would facilitate a broader market penetration of energy management systems that foster continual improvement in the energy efficiency of industrial facilities. The potential energy savings are estimated to range differently in each industry. The breadth of this potential represents the lack of consensus about the magnitude of the opportunity; however, without appropriate policy intervention, most of the energy efficiency potential would not be realized (Jackson, Brown, and Cox 2011). Incentives would include 1) a federal production tax credit for energy-efficiency savings of facilities that become SEP certified; 2) the ability of verified energy savings to be counted as an energy-efficiency credit in compliance with energy portfolio standards; 3) an energy-efficiency grant for 30% of eligible certification costs; and 4) recognition programs. A committed federal policy could lead to cultural changes and market transformation for facilities and service providers, particularly for large firms. The penetration of an energy management system including SEP was started in 2000 in Denmark; Ericsson (2006) indicated that the energy management standards succeeded due to the voluntary agreements and incentive mechanisms. U.S. Secretary of Energy Steven Chu announced the launch of the Global Superior Energy Performance (GSEP) Partnership at the Clean Energy Ministerial in July 2010. GSEP is designed for the global expansion of the SEP program for industrial facilities and has 13 participants including Australia, the European Commission and Japan (Brown et al. 2011b).

Implementation Support Services (ISS) would work with existing Industrial Assessment Centers (IAC) to increase the implementation of energy-saving opportunities identified in IAC energy audits. The IAC program maintains centers at 26 partner universities, with faculty and students performing energy audits on nearby industrial sites. ISS would foster higher implementation rates by leveraging existing relationships between industrial facilities, financial institutions, and engineering firms. Providing this level of technical and business support subsequent to initial IAC energy assessments would not only generate additional energy savings, but would also facilitate the workforce development of undergraduate business students with an understanding and appreciation of energy management. Energy audits of industrial facilities operate in other countries, including Australia, China, Japan and South Korea. Through energy audit programs, industries can identify energy efficiency opportunities and mandate energy efficiency targets and subsequent policies. These partnership programs for carbon intensive industries are similar to ISS in the U.S. (Productivity Commission 2011). Furthermore, Germany has provided grants for energy audits to overcome barriers to energy efficiency such as the lack of energy engineering expertise (Fleiter et al. 2012).

Small Firm Energy Management (SFEM) would provide small manufacturing enterprises (five to 49 employees) with energy management software tools to build in-house capacity to manage energy use and identify potential energy saving opportunities. It would also qualify small firms to be part of IAC assessments. Current DOE programs provide few services and programs tailored to the needs of these important manufacturing enterprises, which are often the crucible of innovation and economic growth. While addressing only a small-percentage of industrial sector energy use, this cost-effective program would allow these small businesses without in-house capacity to reduce their energy bills and carbon footprints, thereby improving their economic viability. The international community has recognized the need to assist the energy management efforts of small and medium businesses. The UK Carbon Trust and Low Carbon Australia provide information and financial assistance to promote the uptake of energy efficiency measures for smaller businesses (Productivity Commission 2011).

The final two policies would tackle financial barriers (blue in Figure 1) by providing new opportunities for accessing capital for energy-efficient systems, equipment, and operations:

Tax Lien Financing of industrial energy-efficiency improvements, also known as Property Assessed Clean Energy (PACE) financing, enables municipalities to establish clean energy taxation districts, which can issue tax-free bonds for certified energy-efficiency and alternative energy projects. PACE financing has been authorized in 28 states,[1] but the focus to date has been on building retrofits and solar energy technologies (Fuller 2010). To address the risk of manufacturing firm closures (particularly during economic recessions), DOE could offer federal loan guarantees to provide security for the bond purchasers and provide a standardized format for the application process. Internationally, there appear to be no perfect analogs, but the Korean Energy Management Corporation (KEMCO) provides low-interest loans for industrial energy-efficiency investments (Environment and Development Division 2001). Additionally, the UK will launch its “Green Deal” program in the fall of 2012, which focuses on efficiency in small businesses and the residential sector: it provides financing through property assessments like PACE, but repayment occurs through energy bills instead of property taxes (UKDECC 2012).

Energy-Efficient Industrial Motor Rebates (IMR), similar to recent U.S. legislative proposals, would authorize and appropriate funding for the DOE to implement a program to provide industrial firms and motor manufactures with rebates for purchases of certified high-efficiency motors of 25 to 500 horsepower that replace motors that predate the Energy Policy Act of 1992. The goal is to accelerate adoption of National Electrical Manufacturers Association premium-rated motors (NEMA 2012). DOE would give priority and additional technical assistance to companies that include motor upgrades as part of a system-wide optimization of their facilities and promote further efficiency measures. India has a corresponding example of this policy, promoting the replacement of conventional motors with energy-efficient motors in industrial firms (Thiruchelvam and Kumar 2003).

1 http://www.dsireusa.org/documents/summarymaps/PACE_Financing_Map.pdf

3. Policy Analysis: The Basic Elements

The seven policies as a whole are designed to complement one another in order to achieve maximum savings. However, each is evaluated individually to determine if it could produce significant and cost-effective energy savings, carbon emissions reductions, if implemented on its own.

3.1 The Magnitude and Value of Energy Savings

Spreadsheet analysis is the main evaluative tool, supplemented by Georgia Institute of Technology's version of the National Energy Management System (GT-NEMS), the Department of Energy's principal energy-economic modeling tool. GT-NEMS was used to evaluate the OBES and EPS policy options because it has a detailed methodology for evaluating the market penetration of CHP technologies in different subsectors of industry. The *Annual Energy Outlook 2010* (EIA 2010) reference case is used as the baseline forecast of the nation's industrial fuel consumption by energy sources out to 2035. Investments stimulated from each policy are assumed to begin in 2011 and to occur through 2035 (or shorter in the case of the Industrial Motor Rebate program, which is a short-term "stimulus" policy). Energy savings are then modeled to degrade at a rate of 5% after 2035, such that all benefits from the policy have ended by 2055.

The value of energy saved by five of the policy options is calculated using the energy price forecasts in the "reference case" described in the *Annual Energy Outlook 2010* (EIA 2010). For example, electricity prices nationwide averaged $25.37/GJ ($26.77/MMBtu) in 2010 and after declining to $23.89/GJ ($25.20/MMBtu) in 2011, they are forecast to increase at a compound annual growth rate of 0.10% to $28.31/GJ ($29.87/MMBtu) in 2035 (in $2009). In contrast, average natural gas prices are projected to rise faster, at a compound annual growth rate of 1.7% from $6.52/GJ ($6.87/MMBtu) in 2011 to $9.99/GJ ($10.54/MMBtu) in 2035 in the same reference case.

For the OBES and EPS policies that are modeled by GT-NEMS, energy prices are an output of the model. Since CHP technologies are fueled principally by natural gas, these policies cause a rise in natural gas prices, which in turn reduces natural gas consumption in other sectors of the economy. Electricity prices, on the other hand, are reduced because cogeneration results in electricity sales to the grid, which replace more expensive electricity generation. Lower-priced electricity in turn results in a slight increase in electricity consumption in other sectors, as would be expected based on the price elasticity of electricity demand (Espey and Espey 2004; Dergiades and Tsoulfidis 2008). Accounting for these correlated factors in a general equilibrium model is one of the strengths provided by GT-NEMS analysis.

Other policies were less amenable to analysis with GT-NEMS, and thus relied on spreadsheet-based models. The SEP, ISS, SFEM, and PACE policies draw heavily from data provided through the U.S. Department of Energy's IAC and Save Energy Now (SEN) programs. IAC audit recommendations are tracked regarding implementation status and reported online in a public database. Over 15,000 assessments have been completed, representing more than 100,000 recommendations (IAC 2010). The IAC program emphasizes small and medium-sized manufacturing (defined as industrial firms with annual energy consumption of less than 530 terajoules, or 500 billion Btus). Save Energy Now focuses on large industrial sites and uses Department of Energy experts to assist these sites in increasing their energy efficiency (Wright et al. 2010). Information from IAC and SEN reports and datasets were used to estimate the cost of energy-efficiency upgrades for the industrial sector of the United States.

To estimate the impact of each policy, GT-NEMS and spreadsheet models were specifically tailored to account for differences and nuances in implementation and design. Baseline assumptions for energy consumption and prices are taken from the *Annual Energy Outlook 2011* (EIA 2011b). GT-NEMS captures the effect on price and consumption as a result of policy changes, resulting in price trajectories that vary from the *Annual Energy Outlook 2011*. For the five policies not amenable to GT-NEMS analysis, we were unable to adjust prices to account for interactions like the rebound effect. However, economy-wide evidence of the rebound effect is limited and the effect appears to be weak (Owen 2010), so the omission of this term is not considered problematic. A brief description of the modeling approach is provided below (See Brown et al. 2011b for a more detailed explanation):

- Output Based Emissions Standards and an Energy Portfolio Standard including CHP are modeled in GT-NEMS. A multivariate fixed effects regression analysis of CHP projects found the adoption of OBES to have a significant impact on CHP installed capacity. Thus, OBES is modeled by increasing the market penetration rate of CHP in GT-NEMS, reflecting nation-wide adoption of OBES by all States within 5 years. Training regulators on OBES is the dominant public cost. The EPS is modeled by decreasing the price of eligible CHP systems within GT-NEMS, representing a 30% investment tax credit that extended through 2035.

- The SEP, PACE, and ISS programs are modeled with the same cost of conserved energy assumptions, as the anticipated savings for these programs cannot be attached to specific fuels. These costs are determined by size of targeted firms, with cost estimates for large firms coming from SEN program analyses and cost estimates for medium and small firms coming from IAC program analyses: these range from $11.9 – $13.3 per GJ ($12.6 - $14 per MMBtu saved).
  - SEP is modeled by assuming 60% of large industrial firms would participate, given sufficient incentives, as described earlier. Government incentives stop in 2035, but firms are modeled as maintaining their commitments into the future.
  - The PACE savings potential is based on the reasons for rejecting recommendations from the SEN and IAC programs and the cost-effective efficiency available in the sector found in the literature. In this model, firms are unable to re-enroll once the initial lien is repaid (representing a lower bound, as such a rule is not anticipated).
  - ISS is modeled as reducing the number of unimplemented recommendations due to financial reasons or that had paybacks greater than two years. The end result is an increase in IAC implementation rates from 37% to 58%.

- SFEM savings are modeled as either electricity or natural gas, and assume small firms implement 40% – 60% of the recommendations, based on historical experience.

- IMR funding levels start at $80 million in 2011 and decline to $60 million by 2015, after which the program stops operating. Estimates of targeted potential annual savings were determined from Nadel et al. (2002) and the DOE MotorMaster+ software (DOE/ITP 2010).

3.2 The Magnitude and Value of Criteria Pollution

Estimated reductions of SO_2, NO_x, $PM_{2.5}$, and PM_{10} emissions are derived by comparing emissions from two sources (the electricity sector and industrial heat production) in the policy scenarios and the *Annual Energy Outlook 2011* reference case. The public health and environmental benefits of reduced emissions of criteria pollutants are evaluated using the damage estimates contained in a recent National Research Council report (NRC 2009). This analysis excludes climate change, mercury, ecosystem impacts, and other environmental damages, but does include public health and crop damages. Altogether, damages caused by criteria pollution from coal power plants are estimated to exceed $62 billion annually. These damages average $33 per MWh in $2008 (NRC 2009).

Natural gas use in the industrial sector also generates significant human health and environmental externalities when combusted to produce heat. NOx emissions are particularly high. In contrast, natural gas used for industrial feedstocks (as in the chemicals industry) have much lower NOx emissions. The NRC report (2009, p.172) concludes that "a very rough order of magnitude estimate of average externalities associated with the industrial sector usage of natural gas is therefore $0.166/GJ, excluding GHG damages. Thus, the six quads of natural gas used for industrial heat would generate about $4,600 million in damage." See Table 1 for a summary of the air pollutant damages associated with emissions from electricity generation and industrial heat production.

Table 1. Criteria Air Pollutant Damages Associated with Emissions from Electricity Generation and Industrial Heat Production ($2008)

	NO_x	SO_2	PM_{10}	$PM_{2.5}$	Total (Equally weighted across plants)	Total (Weighted by net generation of plants)
Natural gas for electricity ($/MWh)	2.39	0.19	0.09	1.76	4.47	1.66
Coal for electricity ($/MWh)	3.53	39.46	0.18	3.12	45.69	33.23
Natural gas for industrial heat $/GJ(cents/MCF)	0.150 (16.25)	0.003 (0.375)	N/A	0.013 (1.375)	0.166 (18.0)	N/A

N/A = Not Applicable.

3.3 The Magnitude and Value of CO_2 Emission Reductions

The carbon dioxide emissions associated with energy consumption are derived from USEPA (2007) and the *Annual Energy Outlook 2011* (EIA 2011b). EIA (2011b) estimates the industrial fuel consumption by source for each year between 2008 and 2035. It also forecasts the changing grid mix over time based on the energy resources used for electricity generation each year. Over time, the electric fuel mix becomes slightly less carbon intensive. We assume the same trajectory of industrial fuel and electric grid mix over time. Using the conversion factors reported by USEPA (2007), we estimate the million metric tons of CO_2 emitted per quad of industrial energy consumption.

Where a policy is anticipated to promote energy efficiency across all fuels (as with the Superior Energy Performance program), the average emissions factor for the entire industrial sector was used. When a policy was more targeted to particular fuels (as with the industrial motor rebates, which only conserve electricity), conversion factors were based on the carbon intensity of individual fuels (Table 2). For the five policies evaluated with a spreadsheet analysis, the electricity saved is expected to have an average fuel mix, and is not based on reduced peak loads.

Table 2. Conversion of Energy Consumption to Carbon Dioxide Emissions

	Million Metric Tons of CO_2 Emitted per Exajoule of Energy Consumed (Million Metric Tons of CO_2 Emitted per Quad of Energy Consumed)		
	2008	2020	2035
Industry Sector Average	46.97 (49.55)	45.81 (48.33)	44.27 (46.71)
Residual Fuel (No. 5 & 6 Fuel Oil)	73.59 (77.64)	73.59 (77.64)	73.59 (77.64)
Natural Gas (Pipeline)	49.55 (52.27)	49.55 (52.27)	49.55 (52.27)
Bituminous Coal	86.87 (91.65)	86.87 (91.65)	86.87 (91.65)
Electricity	55.64 (58.70)	51.18 (53.99)	51.91 (54.77)

Source: Derived from USEPA (2007)

We estimate the financial value of reduced CO_2 emissions in a particular year by multiplying the decrement in emissions by the "social cost of carbon" (SCC) for that year. The SCC is defined as an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. The SCC used in this analysis is based on the central value estimates of the U.S. Government Interagency Working Group on the Social Cost of Carbon (USEPA 2010). In this report, the central value SCC estimates rose from $23/metric ton of CO_2 in 2011 to $34/metric ton and $47/metric ton in 2030 and 2050, respectively (in $2009).

3.4 Policy Evaluation from the Private and Societal Perspectives

The success of energy-efficiency policies in the industrial sector is contingent on motivating manufacturing enterprises to invest private capital and management resources to improving their energy economics. As a result, each of the policies is first evaluated from a manufacturer's perspective to assess the business case for the desired private-sector leverage. A detailed financial analysis of each policy is not feasible because it would require characterizing the tax liabilities and other characteristics of individual firms; however, estimating the up-front private-sector investment costs relative to the stream of energy-expenditure reductions provides a basis for approximating the overall cash-flow attractiveness of each policy to manufacturers.

Two metrics are emphasized: net private benefits and private benefit-cost ratio. On the benefits side of the metrics we include monetized energy savings; on the costs side, we include the private investment. Present-value calculations for the private-sector assessment were conducted using a 7% discount rate to be consistent with Office of Management and Budget guidelines (OMB 2002; 2009), which recommend the use of 3% and 7% discount rates when evaluating regulatory proposals. Since a 10% discount rate is used in some other studies such as McKinsey and Company's analysis (Granade et al. 2009), we also evaluate our results using this higher rate.

The policies are also evaluated in terms of their net societal benefits and their social benefit-cost ratios. On the benefits side of the metrics we include monetized energy savings, CO_2 mitigation, and reductions of criteria air pollutants; on the costs side, we include both the private investments required as well as the public investments and administrative costs. In this paper, as in most detailed Cost-benefit analysis (CBA), different benefit-cost ratios use different combinations of benefits and costs, depending on the purpose of the analysis. Present value calculations for the societal CBA were conducted using a 3% discount rate, with a 7% rate used in sensitivity analyses, consistent with Office of Management and Budget guidelines (OMB 2002; 2009).

4. Policy Design Uncertainties and Stochastic Valuation

It is widely acknowledged that there are large uncertainties associated with estimating the benefits of future levels of energy efficiency and associated changes in CO_2 emissions and criteria pollution. It is essential to provide estimates of key uncertainties, both to avoid any sense of over-precision in the calculated estimates, and to provide stakeholders and policy-makers with usable information for evaluating the risks associated with policy choices. Standard methods for calculating and reporting these uncertainties are only now emerging. In the sections below, we characterize key uncertainties in the context of estimating private and societal benefits and costs.

Incorporating risk and uncertainty in the evaluation of policy options has typically involved two types of approaches. Traditionally, analysts have examined the cost-effectiveness of policies under a range of alternative design configurations, grounded in the desire to advocate the design that appears to deliver the best payback for the public expenditure. More recently, policies have been subjected to statistical analysis of a policy's attractiveness when subjected to a Monte Carlo analysis of uncertainty. Both of these approaches are described below.

4.1 Sensitivity Analysis of Key Policy Design Uncertainties

Key design features of a public policy can evolve before, during and after its implementation. Thus, when proposing a policy initiative, it is useful to evaluate a range of design features to better understand the robustness of the policy to alternative constructions. For instance, does its cost effectiveness depend upon a certain level of participation? Is the level of free ridership a key determinant of success? Do the level and timing of public subsidies and participation rates drive the effectiveness of a policy? Is the amount of energy saved by each participant a key determinant of success? Are there critical parameter values at which estimated net benefits change sign? These are fundamental questions that need to be addressed early in a policy assessment.

Sensitivity analysis usually proceeds by addressing one variable or assumption at a time. Classic examples of using sensitivity analysis in evaluating energy policy initiatives show the typical approach. Sensitivity analysis was used in the well documented case of evaluating a possible EPA standard for reduced lead in gasoline, focusing on the choice of a major reduction versus a total ban, the speed of implementation, and the possible creation of a secondary market for lead rights (Weimer and Vining 2011). In evaluating the development of a strategic petroleum reserve (SPR), sensitivity analysis was used to assess alternative volumetric sizes for the SPR (Dunn 2011). Recently, the Clean Energy Standard (CES) proposed by Senator Jeff Bingaman were analyzed by the Energy Information Administration (EIA 2011a). While the bulk of the analysis performed by EIA focused on the principal policy proposal, sensitivity analyses were also completed to account for a wide range of uncertainties and possible policy designs, ranging from alternative treatments for existing nuclear and hydroelectric generation facilities, giving them either a partial or a full credit for generation to capping the cost of compliance credits and exempting small utilities from complying with the CES. As a result, the range of projected clean energy production is quite wide, from 42% to 80% in 2035.

For each of the seven federal policy options evaluated in this paper, we examine both a principal policy scenario and at least one alternative design addressing key policy features such as the duration of subsidies, speed of implementation, and participation rates. The discount rate used to reduce the value of future benefits and the cost of future investments over time is another cost-effectiveness dimension that is varied. Considering the robustness of policies under alternative assumptions about discount rates is a fundamental component of a thorough sensitivity analysis. As stated in various OMB circulars, analyses should show the sensitivity of the discounted net present value and other outcomes to variations in the discount rate (OMB 2002; 2009).

4.2 Stochastic Representation of Energy Prices and Pollutant Co-Benefits

In addition to design choices, many uncertain variables such as future energy prices and the valuation of pollution externalities also contribute to overall uncertainties in CBA (USEPA 2010). We acknowledge up front that many of those kinds of uncertainty are not readily reducible to probability distributions, except through subjective expert judgment; moreover, whenever human health effects (including mortality) are a substantial component of costs or benefits, the valuation of those effects requires ethical judgments and not simply judgment of likelihoods. For many critics this implies that CBA is simply not a useful tool for decision support in these contexts (Sagoff 1988; Ackerman and Heinzerling 2003). While we have sympathy for the concerns and are well aware that CBA is not sufficient as a decision-making rule (and is not even allowed as a decision rule under the Clean Air Act), as a practical matter the monetization of human health effects is an important element in ongoing decision-making. Thus we believe it is important to develop effective methods for analyzing the various ways in which the numbers produced by CBA are uncertain, and rendering that uncertainty visible in a way that is useful for stakeholder analysis and decision-making. The representation of uncertainty as probability remains one of the best ways to do so.

It is for these reasons that we use Monte Carlo analysis. The quantities that enter into our calculations – program costs, investment costs, energy prices, and pollution damage costs – can all be treated as random variables, defined by deterministic and stochastic components. By representing the stochastic components with probability distributions and treating them as independent, one can aggregate the uncertainty in the various parts of the analysis into a single output distribution for the dependent variable (e.g., the cost-benefit ratio). The simulated distribution for the output variable informs the decision maker of the riskiness of the forecast, and of the skewness of the outcome.

While a complete analysis of uncertainty is not possible, the establishment of effective processes, such as Monte Carlo simulation for determining levels of uncertainty in a specific model contributes to improved reliability and credibility of the model. For this analysis we used Simulation for Excel to Analyze Risk (SIMETAR), an Excel add-in simulation and econometric analysis tool, which is easy to use for processes including multiple regressions, hypothesis testing, time series analysis, and numerous econometric analyses, as well as Monte Carlo simulations.

An obvious limitation to this form of modeling is that, in some of our analyses (specifically the OBES and SEP policies) we are applying post-hoc variation to prices in the CBA of policy scenarios in which the quantities of the relevant variables (e.g., electricity output) and the prices themselves are determined endogenously in the GT-NEMS model. Unfortunately a complex model like GT-NEMS which takes 12 to 24 hours to complete a simulation run on a personal computer is not well suited for Monte Carlo analysis. We justify our approach as a reasonable first order estimate of the contribution of specific risk factors (energy prices, pollution damages) to overall uncertainty in the benefit/cost ratios. Given the heroic assumptions necessary to interpret uncertainties as probability distributions, healthy caution is warranted in interpreting particular values of the output distributions as representing "true" uncertainty. That is to say, for example, that the 95th percentile value we report for the B/C ratio of a given policy is itself uncertain, and would vary, perhaps widely, with any of a score of reasonable alternative assumptions.[2] The sources of this "second order" uncertainty in the outputs extend beyond the Monte Carlo technique to include uncertainty in the parameterization of the input distributions, in the parameters not treated as stochastic, and in the model structure itself. The treatment of this second order uncertainty is important in its own right but is largely beyond the scope of this analysis; for our purposes, since characterizing the full range of this uncertainty is impossible, what matters is that the simplifications we use are demonstrably reasonable, and thus can be more valuable to decision makers than having no such probabilities at all.

[2] Indeed the very premise of Monte Carlo modeling is that, for complex models that can only be run thousands rather than millions of times, the distribution of a particular set of runs is a sample of the "distribution of distributions" based on the random number sequence that is realized, and may itself have a substantial variance of the mean (and of the other moments of the distribution).

Characterizing the uncertainty of key input variables as probability distributions is the first step to incorporate uncertainty in the existing cost and benefit model. As will become evident, there are many possible ways one could characterize the uncertainty of, for example, future energy prices or the SCC, none of which are plainly the "best" such representation. We strive here for a parsimonious model with as few parameters as possible, hoping to gain through transparency what we lose in realism. We begin with the example of energy prices, one of the obviously substantial contributors to the CBA of our proposed policies, especially from the private perspective (excluding externalities).

Energy prices are a perfect example of variables for which future projections are not straightforwardly subject to statistical prediction (Cullenward et al. 2011). Certainly the properties of time series can be used to project forward in a way that is consistent with the historical variability. For example, Vithayasrichareon and MacGill (2012) conclude from historic data from the International Energy Agency that the standard deviation of gas price is best estimated as 30% of the mean, and coal as 10% of its mean. However for complex systems – like that which produces the indicators we call prices – the underlying processes remain unknowable, not least because of their dependence on human choice and innovation. The "true" value at some point in the future is better thought of as an emergent property of a path-dependent system, rather than the realization of a stochastic process.

Nonetheless, our representation of a pathway of future prices in time as a function in two-dimensional space lends itself to modeling of uncertainty as a band or envelope of future pathways. By parameterizing a simple function appropriately, a Monte Carlo simulation can be used to create a range of single realizations that generate a band with the appropriate variability and central tendency; and, crucially, by parameterizing multiple variables in this fashion, the uncertainty implicit in the various bands can be combined into an overall aggregate uncertainty represented as a probability.

Indeed, given the many issues associated with interpreting the "input" variables probabilistically, one could argue that sensitivity analysis using plausible alternative values for key parameters is a more important tool than Monte Carlo analysis. For example, in some cases one could simply run the same policy exercise in GT-NEMS using the parameters from the alternative (e.g., high coal cost or high technology) scenarios. However, only in a Monte Carlo analysis can one see how the uncertainties in different variables combine, and judge the relative contribution of the uncertainty in different model input assumptions to the uncertainty in the output (dependent) variable of interest.

Our approach, then, is to come up with simple representations of the key input variables that can be used in a Monte Carlo analysis. As a practical matter we have three broad kinds of variables.

1) Energy prices are assumed to have an uncertain time trend and which can be considered to trace out a "band" or "envelope" around the reference case pathway, starting from a known price in the current year.
2) Damage costs from criteria pollutants are assumed to be uncertain but not to have strong time trends, and thus can be treated as stochastic but constant values.

3) The SCC is both uncertain in the present and can be assumed to grow at a rate that is also uncertain.

In the following section, we detail the assumptions we use to translate these characterizations of uncertainty into numerical values.

Energy Prices. Given that we are using the EIA's reference case assumptions for *Annual Energy Outlook 2011* (EIA 2011b) to drive our GT-NEMS and spreadsheet modeling, we take the upper and lower bounds of the various alternative cases in *Annual Energy Outlook 2011* (EIA 2011b) as reasonable (albeit conservative) indicators of the spread of future energy prices. More specifically, we calibrate a simple exponential function with three parameter values that reproduce the 2030 values from the reference case and the selected high and low alternative scenarios for each energy type, and then generate a distribution of pathways using a GRKS distribution (see below) for the annual growth rate as an input to Monte Carlo simulation.

Our reference case forecast of industrial electricity prices comes from the Industrial Sector Key Indicators and Consumption table in *Annual Energy Outlook 2011* (EIA 2011b). It provides the baseline for our policy analysis. Alternative scenarios are generated by varying the reference case assumptions. For example, the high technology case assumes earlier availability, lower costs, and higher energy-efficiency for more advanced energy production and end-use equipment. Energy price trends in the high technology case are likely to remain the lowest among all alternative scenarios. Another scenario is the high coal cost case, where the average annual productivity growth rates for coal mining are lower than those in the reference case. Several costs, including coal mining wages, mine equipment costs, and other costs, are assumed to be about 28 percent higher than in the reference case; thus, the high coal cost case is likely to have the highest electricity prices.

Electricity prices decrease from $17.92/GJ ($18.91/MMBtu) in 2010 to $17.00/GJ ($17.93/MMBtu) in 2011 and then increase gradually to $17.75/GJ ($18.73/MMBtu) in 2035 in the reference case. Together with the reference case, the high technology and high coal cost cases are used to calculate growth rates for 2012 to 2035. The calculated growth rates are 0.17% (high technology case), 0.68% (reference case) and 0.91% (high coal cost case), respectively (Figure 2).

Natural gas prices are projected to increase from $4.55/GJ ($4.80/MMBtu) in 2010 to $6.83/GJ ($7.21/MMBtu) in 2035 in reference case. Three cases are used to calculate growth rate for 2012 to 2035. The calculated growth rates are 0.96% (high technology case), 1.57% (reference case) and 1.65% (high coal cost case), respectively (Figure 2).

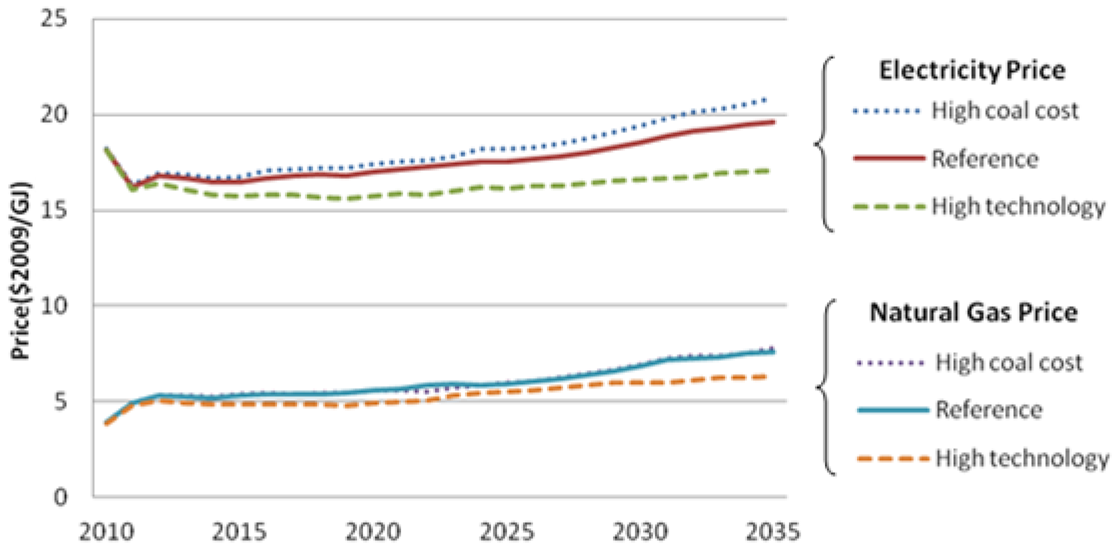

Fig. 2 Electricity and Natural Gas Price

Using three growth rates that recreate the low, median and high values in 2035, we can parameterize a modified triangular distribution called the GRKS distribution after for its developers, Gray, Richardson, Klose, and Schuman (Richardson 2008). The GRKS distribution was built in SIMETAR and is used to represent a continuous distribution when dealing with limited information about the random variable. Given a minimum, median, and maximum value, like three growth rates, we can define a probability distribution. Its minimum and maximum need not be located equidistant from the middle value, so the GRKS distribution can be a skewed distribution. It draws 2.28% of the values from below the minimum and 2.28% above the maximum to incorporate rare unexpected events; that is the minimum and maximum are treated as approximately two-sigma values, with small but non-zero probability outside their range. This generates plausible tails to the distribution in a way that takes account of the asymmetry of the input values.

The growth rate of electricity prices is simulated with a GRKS distribution with a minimum value of 0.17%, a median value of 0.68%, and a maximum value of 0.91%. Due to the variability of the growth rate, the uncertainty of the price path increases over time, as shown in the fan graph in Figure 3. The 90% confidence interval (between the 5^{th} and 95^{th} percentiles) in 2035 is approximately the same as between the highest (high coal cost) and lowest (high technology) scenarios in *Annual Energy Outlook 2010* (EIA 2010). The deterministic electricity prices in the spreadsheet models for calculating cost/benefit ratios are replaced with these stochastic prices.

For natural gas, the minimum growth rate is 0.96%, the median (reference case) is 1.57%, and the maximum is, 1.65%. The distribution of the stochastic growth rate is left skewed. Simulated natural gas prices are presented in Figure 3 to describe the increasing variability over the years. Unlike electricity prices, stochastic natural gas price are expected to increase substantially. Deterministic natural gas prices in the spreadsheet models are also replaced by stochastic natural gas prices.

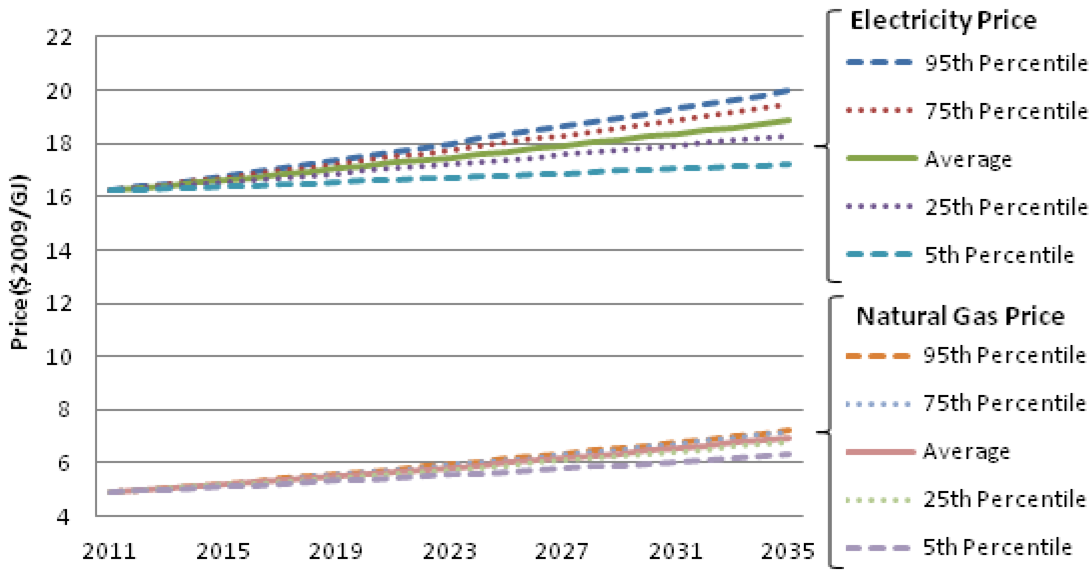

Fig. 3 Fan Graph of Stochastic Electricity and Natural Gas Price

Criteria Pollutants. Stochastic modeling of four criteria pollutants (SO_2, NO_x, $PM_{2.5}$ and PM_{10}) is conducted by using the range of values shown in Table 3, which is drawn from NRC (2009). As detailed in NRC (2009), the uncertainties shown arise from plant-level differences in emissions and geography; additional uncertainties would arise if variations in valuation assumptions or transport modeling were also included (Muller 2011). However, for a first-order estimate of overall uncertainty we use the 5th, 50th and 95th percentile values as the minimum, median, and maximum in parameterizing a GKRS distribution; the mean and standard deviation calculated from this parameterization are shown in the rightmost columns. These stochastic values are then linked to the CBA calculations in our spreadsheet models.

Table 3. Distribution of Criteria Pollutant Damage Values

Distribution of Criteria-Air-Pollutant Damages per Kilowatt-Hour Associated with Emissions from 406 Coal-Fired Power Plants in 2005 (2007 $/MWh)							
	Mean	Std dev.	5th percentile	50th percentile	95th percentile	**Simulated Mean (GRKS)**	**Simulated Std Dev (GRKS)**
SO_2	38	41	2.4	25	119	**39.6**	**31.5**
NO_x	3.4	3.8	0.73	2.3	9.1	**3.4**	**2.3**
$PM_{2.5}$	3	4.4	0.19	1.3	11	**3**	**3**
PM_{10}	0.17	0.23	0.01	0.08	0.6	**0.17**	**0.17**
Distribution of Criteria-Pollutant Damages per Kilowatt-Hour Associated with Emissions from 498 Gas-Fired Power Plants in 2005 (2007 $/MWh)							
	Mean	Std dev.	5th percentile	50th percentile	95th percentile	**Simulated Mean (GRKS)**	**Simulated Std Dev (GRKS)**
SO_2	0.18	0.67	0.0013	0.022	0.75	**0.17**	**0.22**
NO_x	2.3	7.4	0.014	0.38	10	**2.3**	**2.9**
$PM_{2.5}$	1.7	5.6	0.0029	0.26	7.5	**1.7**	**2.2**
PM_{10}	0.09	0.29	0.0003	0.014	0.36	**0.08**	**0.1**

Commercial Sector Natural Gas Use for Heat: National Damage Estimates from Air Pollutants (Excluding Greenhouse Gases) 2007 $/GJ (cents/MCF) (Damage Estimated from 2002 NEI Emission Data for 3,100 Counties)							
	Mean	Std dev.	5th percentile	50th percentile	95th percentile	**Simulated Mean (GRKS)**	**Simulated Std Dev (GRKS)**
SO_2	0.003 (0.3)	0.012 (1.3)	0.001 (0.06)	0.002 (0.2)	0.007 (0.8)	**0.003 (0.29)**	**0.002 (0.2)**
NO_x	0.120 (13)	0.323 (35)	0.032 (3.5)	0.083 (9)	0.250 (27)	**0.107 (11.54)**	**0.058 (6.27)**
$PM_{2.5}$	0.010 (1.1)	0.176 (19)	0.001 (0.07)	0.002 (0.26)	0.016 (1.7)	**0.005 (0.51)**	**0.004 (0.46)**

Source: NRC (2009), Tables 2-9, 2-15, and 4-4.

Social Cost of Carbon. Uncertainty in the SCC has been a topic of substantial discussion, with published values ranging from negative values to many hundreds of dollars per ton of carbon dioxide (Tol 2005). Some of the largest costs occur when the damages of climate change are characterized as being right skewed with fat tails – the so-called “dismal theorem” of climate change (Weitzman 2009). Again, for a reasonable and parsimonious estimate of uncertainty, we base our range on the values recommended in the U.S. Government Interagency Working Group of the Social Cost of Carbon (USEPA 2010). In that report, four different pathways for the SCC were shown, with values in 2010 ranging from $4.83/metric ton to $67.50/metric ton, and annual growth rates ranging from 1.54% to 3.02%. In the deterministic calculations reported above, we used the central case; for our uncertainty analysis we used the low and high values as the minimum and maximum and the central case as the median to parameterize two GRKS distributions, one for the 2010 value and one for the growth rate. The fan graph in Figure 4 shows the results of combining these uncertainties in projecting the time path of the SCC.

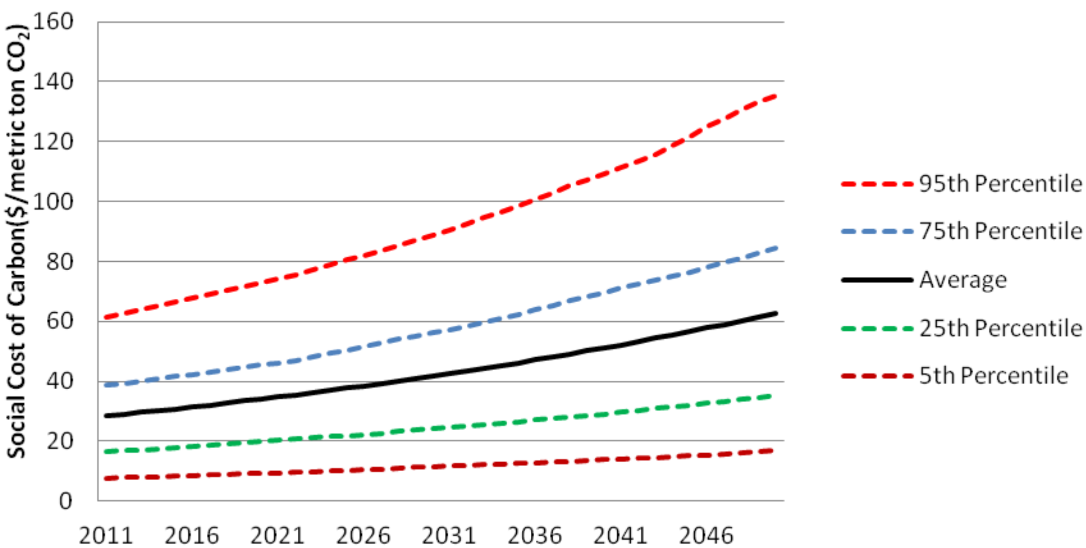

Fig. 4 Fan Graph of Stochastic Social Cost of Carbon

5. Results

5.1 Private Perspective on Cost-Effectiveness

From the private perspective, our analysis indicates that each of the seven public policy options for promoting energy-efficiency in the industrial sector would be cost-effective for manufacturers. The present value of the stream of energy-expenditure reductions exceeds the present value of the manufacturer's up-front investment costs using a 7 percent discount rate. As shown in Table 4, this conclusion is supported by both deterministic and stochastic calculations based on the methodologies described in Section 4. For our purposes we treat the investment costs as fixed and the energy savings as stochastic because of the uncertain nature of future energy prices. In reality, investment costs can also vary significantly as has been seen in recent years with the increase in the price of steel and industrial boilers and burners, which occurred in the economic boom preceding the 2008 global recession. At the same time, expanded deployment of a next generation of energy-efficient equipment encouraged by public policies could lead to reduced production costs through economies of scale. These uncertainties were not modeled.

Focusing first on the deterministic results shown in Table 4, a federal policy promoting output-based emissions standards offers the largest net private benefits because the present value of energy savings attributed to the policy ($142 billion through 2055) far exceeds the associated private investment of $19 billion. Its private benefit-cost ratio, on the other hand, is not the highest among the policy options, because it does not involve any public subsidies. The Superior Energy Performance program and Energy Portfolio Standard have higher benefit-cost ratios, partly as a result of including public subsidies that offset 30% of investment costs.

At the lower end of the benefits scale, the Industrial Motor Rebates program saves manufacturers $908 million in energy costs, but it requires a private investment that is also large, at $220 million. Thus, it has the smallest net present value to manufacturers and one of the smallest private benefit-cost ratios. Designed to provide rapid economic stimulus with rebates to support motor upgrades, its benefits come early, and its benefit-cost ratio in 2015 is higher than most of the other policies.

Figure 5 illustrates the results of the stochastic analysis from the manufacturer's perspective. It uses box and whisker plots to portray the variability, with the bottom and top of the box defined by the 25th and 75th percentile (the lower and upper quartiles, respectively), and the band near the middle of the box denoting the 50th percentile (the median). The ends of the whiskers represent the minimum and maximum of all the data. The fact that the whiskers above each box are only slightly longer than those below each box reflect the near symmetry of the probability distribution for natural gas and electricity prices: we estimate that energy prices are almost as likely to fall below the forecast as they are to escalate above the forecast over the next 25 years.

The box plots also highlight the greater variability in net private benefits associated with the two policies that promote combined heat and power (OBES and EPS). The significant uncertainty is a function of the broader range of possible future natural gas prices (reflecting their historic volatility) compared with electricity prices, which have been more stable in the U.S. In the stochastic analysis, the higher natural gas prices disadvantage EPS less than the OBES policy because its increase in natural gas consumption is much more modest (i.e., in 2035, EPS consumes approximately one quad more natural gas than in the reference case, while OBES consumes 2.5 quads more). The EPS policy also benefits more from electricity savings. These impacts cause the substantial difference in CBA metrics under the deterministic versus stochastic analysis.

Table 4. Private Cost-Benefit Analysis*

Industrial Energy Efficiency Policy	**Cumulative Private Benefits (Energy Savings)****		**Cumulative Private Cost**	**Private Benefit-Cost Ratio**		**Net Private Benefits (Billions $2009)**	
	PJ (Trillion Btu)	(Billions $2009)	(Billions $2009)	Deterministic[a]	Stochastic[b]	Deterministic[a]	Stochastic[b]
Output Based Emissions Standards	21,733 (20,600)	142	18.8	7.5	9.34 (1.29) 7.2-12.2	123	157 (16) 116-210
Energy Portfolio Standard With Combined Heat and Power	10,339 (9,800)	19.9	1.9	18.5	36 (8.6) 13-64	33.8	67.4 (17) 24-122
Superior Energy Performance	51,484 (48,800)	89.2	10.2	8.7	8.6 (0.1) 8.2-8.8	79	77.5 (1.1) 74-80
Implementation Support Services	3,598 (3,410)	8.2	2.2	3.7	3.7 (0.03) 3.6-3.7	5.9	5.9 (0.08) 5.6-6.0
Small Firm Energy Management	997 (945)	3.6	0.58	6.2	6.3 (0.13) 5.81-6.57	3.0	3.1 (0.074) 2.7-3.2
Tax Lien Financing	10,557 (10,007)	37.9	6.6	5.8	5.8 (0.02) 5.67-5.80	31.3	31.2 (0.157) 30.7-31.5
Energy Efficient Industrial Motor Rebates	70.5 (66.8)	0.91	0.22	4.1	4.13 (0.03) 4.03-4.19	0.7	0.7 (0.063) 0.66-0.7

*Present value of costs and benefits were calculated using a 7% discount rate.
**Investments stimulated from the policy occur through 2035. Energy savings are then modeled to degrade at a rate of 5% after 2035, such that all benefits from the policy have ended by 2055.
[a]Using 10% discount rates, the private B-C ratio decreases for six out of seven policies: OBES(7.5 to 6.6), EPS (18.5 to 15.4), SEP (8.7 to 8.1), ISS (3.7 to 3.2), SFEM (6.2 to 6.2), and IMR (4.1 to 3.9). However, the private B-C ratio of PACE increases because of high initial investment cost, 5.8 to 6.1.
[b]Stochastic values include the mean, standard deviation in parentheses, and the minimum and maximum.

Based only on the merits of the energy bill savings and the incremental investment costs associated with industrial energy-efficiency upgrades, all seven of these energy efficiency policies are attractive from a private accounting perspective. This holds true when both a 7% and a higher (10%) discount rate is used. A more complete analysis of the private benefits of industrial energy-efficiency investments would likely increase the benefit-cost ratios shown in Table 4. There is a growing recognition that energy-efficiency improvements produce many "non-energy" benefits, including reduced operating and maintenance costs, increased production yield, safer working conditions, water savings, and waste minimization (Worrell et al. 2003; Prindle 2010). A review of 70 industrial case studies concluded that in a majority of cases, these collateral benefits are equal to or exceed the value of the energy savings (Worrell et al. 2003). Energy-efficiency upgrades are not being made because of various market failures, which warrant the implementation of public policies such as these. The rationale for the seven energy-efficiency policies is persuasive from a private perspective and increases when societal costs and benefits are considered.

5.2 Societal Perspective on Cost-Effectiveness

Table 5 compares the estimated total social cost of each policy (including both public and private costs) with the value of its anticipated social benefits based on energy savings, pollution prevention, and avoided carbon dioxide emissions. In this table, we calculate the total net social benefits by subtracting the present value of the private and public costs from the present value of the benefits using a 3% discount rate. The result for each of the seven policies is a positive net social benefit, meaning that the present value of the benefits exceeds the present value of the private and public costs. Again, both deterministic and stochastic calculations are presented.

Similar to the analysis of cost-effectiveness from the manufacturer's perspective, the societal perspective suggests that a federal policy promoting output-based emissions standards would offer the largest net social benefits, followed by the Superior Energy Performance program. Both policies also have high social benefit-cost ratios. OBES also has the lowest public costs since it only principally involves providing regulatory assistance to states; as a result, it would appear to be particularly attractive with today's fiscally constrained federal budget.

For both of these policy options, energy savings account for approximately two-thirds of the estimated total social benefits. The next largest source of social benefit comes from avoided criteria pollutant emissions, followed by the value of avoided carbon dioxide emissions. Where the policies emphasize natural gas consumption (OBES and EPS), the benefits of avoided CO_2 are less than half of the benefits of avoided criteria pollution. Where the energy savings come principally from electricity, which is entirely the case with energy-efficient industrial motor rebates, the value of avoided carbon dioxide and criteria pollution are comparable.

Tax Lien Financing and Small Firm Energy Management also would generate significant net societal benefits and have moderately high benefit-cost ratios, estimated at 6.3 and 7.8, respectively. As is the case from the manufacturer's perspective, motor rebates offer the smallest net societal benefits and benefit-cost ratios, but they are nonetheless favorable and a higher proportion of their benefits occur in the first several years compared with the other six policies.

Table 5. Social Cost-Benefit Analysis*

Industrial Energy Efficiency Policy	Cumulative Social Benefits (Billions $2009)				Cumulative Social Costs (Billions $2009)			Social Benefit-Cost Ratio		Net Societal Benefits (Billions $2009)	
	Energy Savings	Value of Avoided CO_2	Value of Avoided Criteria Pollutants	Total Social Benefits**	Public Costs	Private Costs	Total Social Costs**	Deterministic	Stochastic[a]	Deterministic	Stochastic[a]
Output Based Emissions Standards	232.1	25.9	66.1	324.2	0.0	25.5	25.5	12.7	15.1 (2.6) 9.5-25.4	299	358 (67) 217-621
Energy Portfolio Standard With Combined Heat and Power	40.9	11.6	27.0	79.5	11.6	2.8	14.4	7.4	11 (2.6) 4.5-20	95.6	146 (38) 51-277
Superior Energy Performance	197	40.8	57.7	307	2.16	17.0	19.2	16.0	16.4 (2.5) 11.5-25.2	288	295 (48) 201-463
Implementation Support Services	15.2	3.0	5.0	23.2	0.49	3.29	3.8	6.1	6.3 (1) 4.5-9.6	19.4	20 (4) 13-32
Small Firm Energy Management	7.2	0.9	0.8	8.9	0.24	0.88	1.12	7.8	8.02 (0.75) 6.67-10.9	7.6	7.85 (0.84) 6.35-11.08
Tax Lien Financing	49.5	10.1	18.5	78.2	3.01	9.4	12.39	6.3	6.55 (1.17) 4.5-10.6	71.9	74.6 (13.3) 51.7-121
Energy Efficient Industrial Motor Rebates	1.05	0.08	0.13	1.25	0.33	0.23	0.57	2.21	2.25 (0.18) 1.87-2.91	0.68	0.7 (0.1) 0.5-1.1

*Present value of costs and benefits were calculated using a 3% discount rate.

**Total costs and benefits do not include various non-monetized values (e.g. mercury pollution reduction, increased productivity, water quality impacts, etc.).

[a]Stochastic values include the mean, standard deviation in parentheses, and the minimum and maximum.

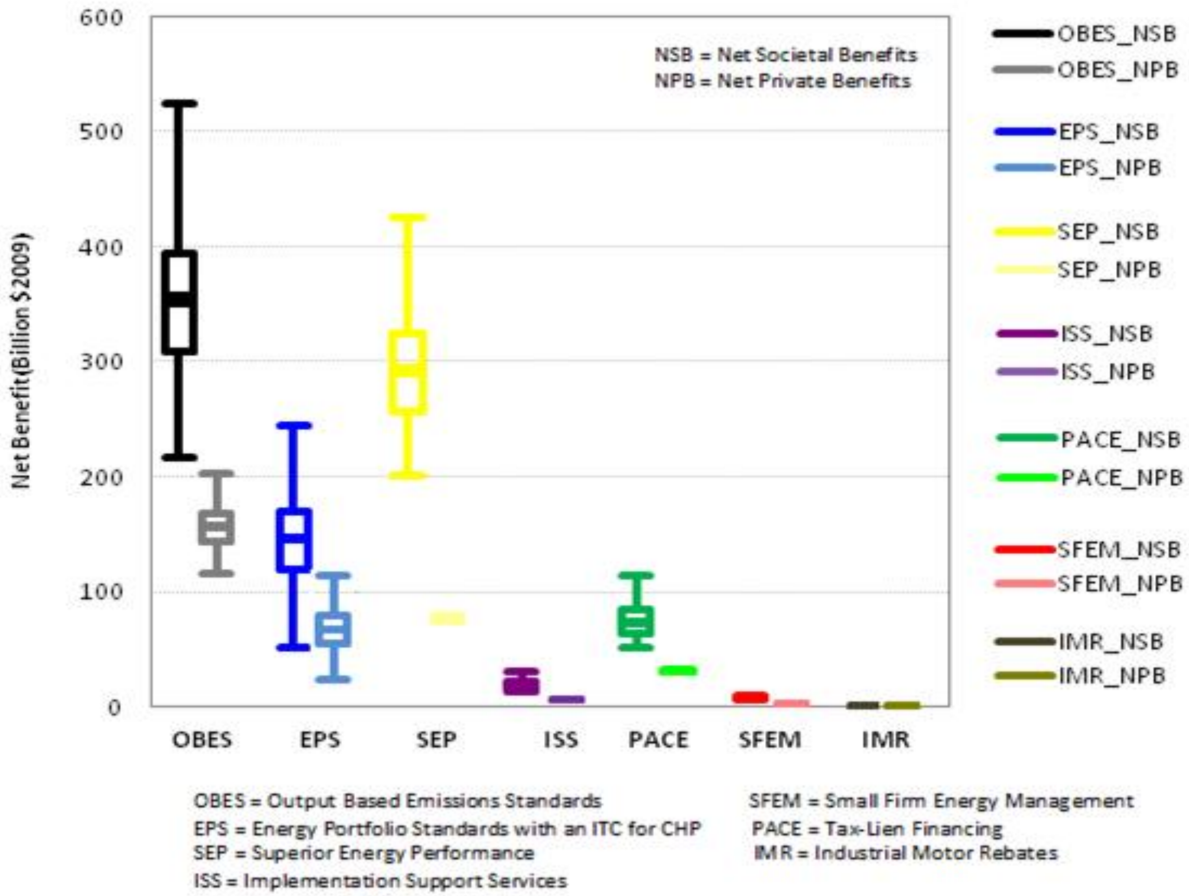

Fig. 5 Box and Whisker Plot of Net Private Benefit (NPB) with 7% discount rate and Net Social Benefit (NSB) with 3% discount rate

The box and whisker plots visually present estimates of the ranges of net social benefits for the seven policies (Figure 5). The fact that the bottom whiskers are shorter than the top whiskers indicate that the net social benefits for each of the policies are skewed to the right; that is, the bulk of the values are lower than their means, and this is offset by a smaller number of relatively high values. This is due to the probability distributions of the benefits from avoided CO_2 and criteria pollution. These skewed distributions suggest that there is a small probability that the net social benefits of these energy-efficiency policies could be extremely large.

As was true with the net private benefits, significant uncertainty is associated with the cost-effectiveness of the two policies promoting combined heat and power. This large uncertainty reflects the range of possible future natural gas prices combined with the stochastic nature of the pollution-reduction benefits derived from displacing coal and oil boilers with cleaner fuels and more efficient electricity production. Unlike the CBA from the private perspective, there are also significant uncertainties surrounding the net social benefits of the other policy options, as well. This reflects the highly stochastic nature of the benefits from avoided CO_2 and criteria pollution that are associated, in particular, with reductions in fossil-generated electricity resulting from more energy-efficient manufacturing.

5.3 Sensitivity Analysis of Key Risk Factors

For each of the seven policies, we completed a sensitivity analysis of key risk factors, examining specific alternative assumptions related to alternative policy designs, discount rates, and natural gas prices. We use the societal perspective, where: (1) costs include public and private investments, and (2) benefits include energy savings and damages avoided from criteria pollutants and carbon dioxide emissions. We complete three pairs of CBA:

- The first pair assumes the principal policy design and applies a 3% and a 7% discount rate.
- The second pair assumes an alternative policy design and again uses a 3% and a 7% discount rate.
- The third pair assumes that natural gas prices are 2 standard deviations above or below the mean forecasted price.

This range of gas prices exceeds the ranges based on historic studies and is outside the bounds of the fan graph shown in Figure 5. We elect to examine far greater uncertainty in future gas prices based on the recent emergence of shale gas, which may succeed or fail to become a major new source of future gas (IEA 2011). For example, in 2020, natural gas prices in the reference case for OBES and EPS at 2 standard deviations below the mean are $2.20/GJ ($2.32/MMBtu) and at 2 standard deviations above the mean are $6.61/GJ ($6.97/MMBtu).

As expected, social benefit-cost ratios are generally higher for the seven policies when lower discount rates are used, since up-front investment costs are offset by years of energy savings that are more significant when discount rates are low. The natural gas price sensitivity, on the other hand, is highly variable and has the opposite effect for some policies. Specifically, the two policies that promote combined heat and power experience the greatest range of cost-effectiveness reflecting the higher risk that natural gas prices pose to their cost-effectiveness. The lowest natural gas prices produce social benefit-cost ratios of 18 for OBES and 30 for EPS, while the highest prices produce ratios of 7 and 8, showing that these two policies still pass this severe stress test. The other five policies are more cost-effective when natural gas prices are high because they are reducing energy consumption by implementing efficiency measures, so higher gas prices drive up their energy-savings benefits.

Several additional insights resulted from the analysis of key policy design uncertainties, showing the power of this additional examination of risk factors.

- We consider a rapid (five-year) state adoption period for output-based emissions standards in the principal policy versus a slow (ten-year) adoption period in the alternative case. The PACE sensitivity was also slower than its principal formulation (a 20-year versus a five-year adoption period). These sensitivities highlight the net social benefit of more rapid policy implementation.

- We evaluate an EPS supported by an investment tax credit that operates for 24 years (in the principal policy) but consider 10-year duration in a sensitivity analysis. This sensitivity analysis highlights the greater societal benefits of the 24-year ITC, but it also shows that the shorter ITC has a more attractive benefit-cost ratio because of the lower level of free ridership. As a result, the 10-year policy sensitivity outperforms the 24-year subsidy in terms of societal benefit/cost ratios. The energy saved by free riders, who would have adopted these programs without the supporting policies, are not included in the benefit totals, but they do impact the public costs when subsidies are provided to such firms.

- Three of the sensitivities model lower levels of market penetration, underscoring the value of striving for deeper and more widespread efficiency investments. In the SEP program, 40% of facilities are assumed to adopt the SEP program in the principal policy, but the policy sensitivity assumes a lower penetration, at 20% of large facilities. The benefit/cost ratios are comparable for these two designs, but the net societal benefits are twice as large when the higher market penetration is achieved. Similarly, we evaluate the difference between assuming a rate of penetration of 60% of recommended measures by small firms participating in the SFEM program (in the principal case) versus 40% penetration in the alternative case, and we assume a lower level of funding and fewer participants for the Implementation Support Services program as an alternative. The impact on the CBA metrics is similar.

- For the industrial motor rebates program, the principal policy assumes that firms will purchase new motors rather than fix new standard motors five years earlier than would have otherwise occurred without the rebate, while the sensitivity assumes ten-year acceleration. The 10-year acceleration sensitivity produces greater savings and higher benefit-cost ratios not because it replaces more motors, but because it is assumed to replace inefficient motors that would otherwise have operated for ten years, rather than only five.

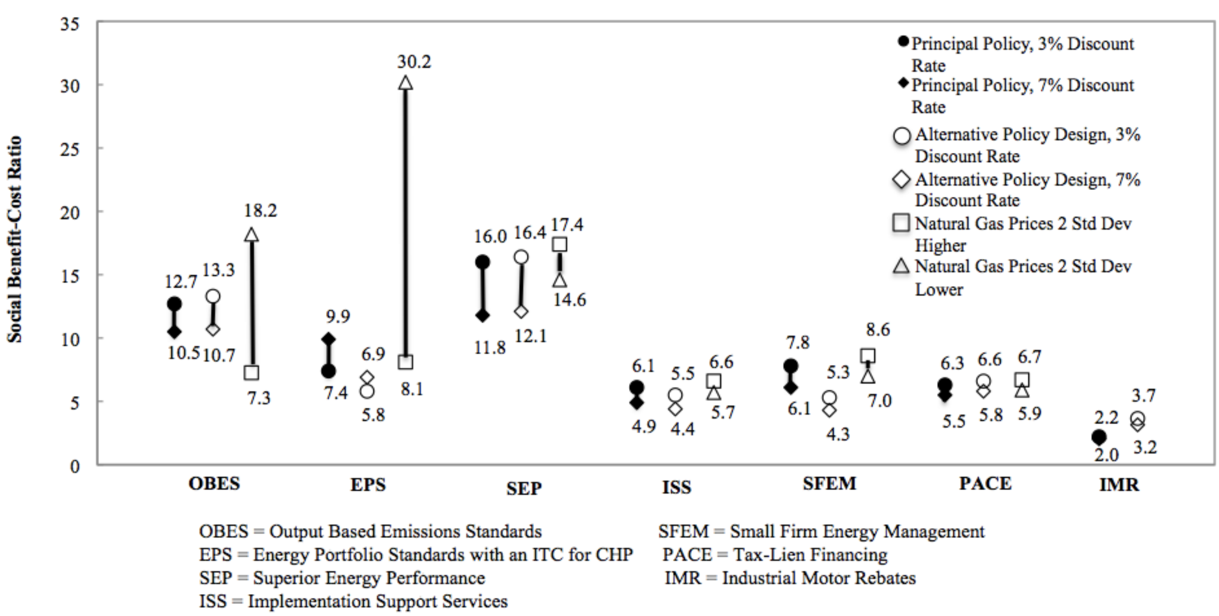

Fig. 6 Sensitivity Analysis of Key Risk Factors Using Social Benefit-Cost Ratios

Benefits of the seven policies are not additive, as the policy initiatives can overlap in addressing identical markets, opportunities, and barriers. Policies can also work synergistically, addressing bundles of obstacles thereby producing more benefits when they are implemented in a coordinated fashion, as could happen for instance with workforce development programs combined with financial incentives and regulatory reforms. Bundles of obstacles often hinder energy efficiency, as has been shown in many empirical studies (e.g., insufficient interest of manufacturers of machinery and plants to offer high efficient solutions; incomplete knowledge of planners, consulting engineers and energy managers; inadequate decision routines in companies; and capital rationing that reflects risk and uncertainty) (Brown, et al, 2011b). Cost effectiveness also involves assessing the overall public costs of each policy and the ability of these public investments to leverage energy savings and carbon dioxide emission reductions. The focus on overall government costs is particularly important given current concerns regarding public deficits and the desire to constrain government spending.

5.4 Summary Assessment of Policies

Each of these seven policy options has an appropriate federal role and broad applicability across industries. They utilize readily available technologies (or new technologies that will be available over the course of the implementation period), are administratively feasible, and have additionality and synergy with other efforts. Other strengths are the market transformation impact of the Superior Energy Performance program, the development of information technology products for Small Firm Energy Management, and the additionality of tax lien financing. Output-Based Emissions Standards have a narrow focus on a single technology (CHP), and a federal Energy Portfolio Standard might have many free riders, but the CBA is nonetheless highly favorable. Although the Industrial Motor Rebates have relatively high public costs, their benefits exceed their costs under a range of plausible assumptions. A generalized stakeholder assessment indicates that industrial firms, service providers, and others would support these policy options, while many of those utilities that might experience revenue erosion from these energy-efficiency initiatives, might consider them undesirable (Brown et al. 2011b).

A more complete analysis of the impacts of industrial energy-efficiency investments might increase the social benefit-cost ratios of these policies. There is a growing literature that documents several categories of "non-energy" financial benefits including reduced operating and maintenance costs, improved process controls, increased amenities or other conveniences, water savings and waste minimization, and direct and indirect economic benefits from downsizing or elimination of other equipment (Prindle 2010). Our analysis also does not include externalities associated with the extraction of fuels (including environmental and public health externalities) (Pond et al. 2008; Bernhardt and Palmer 2011) or transmission and distribution (Sovacool 2008). On the other hand, the avoidance of environmental damages that contributes to the high societal benefit-cost ratios of these seven policies could be overstated if EPA regulations are tightened over the next several decades and if a price is put on the cost of carbon. Those two actions would produce many of the social benefits that, in their absence, would be important benefits of the seven policies evaluated in this paper.

6. Conclusions

The energy-efficiency gap in the U.S. industrial sector is large. Our analysis suggests that policies could help motivate businesses to focus more of their resources on "leaner" manufacturing systems. With the right policy environment, industry could shrink its energy-efficiency gap and become a bigger part of the climate solution while at the same time strengthening its competitiveness and maintaining domestic jobs. The deterministic calculations of cost-effectiveness suggest that the seven policies would also be highly desirable both from the calculus of a private investor such as an industrial entrepreneur and from the perspective of society.

The uncertainty analysis, on the other hand, highlights the degree that these favorable benefit/cost calculations could be challenged by the occurrence of low-probability extreme events. For example, if natural gas prices were to surge, the private sector would benefit significantly less from a large commitment to natural gas-powered combined heat and power systems. Similarly, if the benefits of climate remediation prove to be negligible, then the social benefit-cost ratio of these policies would not be as appealing. By incorporating risk factors that manufacturers and policy-makers cannot forecast with certainty, we have examined the robustness of these seven industrial energy efficiency policies. Overall we conclude that the societal cost-effectiveness of policies is generally more sensitive to alternative assumptions about damages from criteria pollutants and climate change compared with energy prices; however, risks also vary across policies based partly on the technologies they target. Nevertheless, for the range of uncertainties we believe to be plausible, the federal policy options examined here for promoting industrial energy efficiency remain attractive under an array of stress testing.

Future research needs to examine the macroeconomic consequences of the choice between a lethargic approach to energy waste and modernization in manufacturing versus a vigorous commitment to industrial energy productivity and innovation. If U.S. industry does not pursue much greater levels of energy efficiency and innovation, the U.S. economy may become considerably less robust. In contrast, if industrial energy efficiency and innovation were to materialize at the scale envisioned in Figure 1, U.S. manufacturing could experience the kind of renaissance that would produce far-reaching economy-wide benefits extending well beyond those evaluated here.

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