Incorporating Risk and Uncertainty in Cost-Benefit Analysis

Sener Salci*
Department of Economics, Queen's University, Kingston ON, Canada
sener.salci@gmail.com

Glenn P. Jenkins
Department of Economics, Queen's University,
Kingston, Ontario, Canada, K7L3N6,
Department of Economics, Eastern Mediterranean University,
Mersin 10, Turkey
jenkins@econ.queensu.ca

Development Discussion Paper: 2016-09

* Corresponding authors at: Department of Economics, Queen's University, Kingston, ON, Canada K7L 3N6 / e-mail addresses: sener.salci@gmail.com (S. Salci) and jenkins@econ.queensu.ca (G.P. Jenkins)

ABSTRACT

Cost-Benefit Analysis (CBA) is a tool for assessing the welfare effects of changes in regulatory and investment interventions. While in many ways an effective approach, a significant drawback of CBA, however, is that it relies on estimates for variables that cannot be predicted with complete accuracy. As such, expected outcomes generated by CBA, such as financial and economic net present values (NPVs), incorporate a degree of risk and uncertainty. It is therefore critical that CBA is based on transparent assumptions about the nature of risk and uncertainty affecting key variables: CBA cannot contribute to rational decision-making unless the distribution of outcomes is clear, and the effect on forecast reliability understood.

Real-world risk and uncertainty generate numerous ex-ante outcomes at the point of appraisal. Correctly assessing risk and uncertainty is therefore one of the most difficult challenges decision-makers face in applying the results of CBA. This report offers a systematic approach to the incorporation of risk and uncertainty in CBA. The primary objectives are to review the professional literature on risk and uncertainty; to provide a methodology for taking account of risk and uncertainty in CBA; and to suggest guidelines for the interpretation and application of CBA results in the decision-making process.

The treatment of risk and uncertainty are clearly addressed in the CBA guidelines of most OECD countries, although approaches vary. The simplest procedures are based on sensitivity analysis, as applied to a deterministic base case. More comprehensive analysis is based on assumed probability distributions for the variables concerned. The CBA guidelines of multilateral financial institutions and a number of advanced economies (Australia, Canada, France, the UK, the US and the European Union) call for sensitivity analysis on a project-by-project basis, identifying specific long-term risks and uncertainties associated with the assumptions and values used in appraisal and evaluation.

Still greater insight into the impact of risk and uncertainty on expected regulatory outcomes can be gained from a probabilistic modeling of variable distributions and their inter-dependencies. A Monte Carlo simulation is therefore recommended alongside sensitivity analysis, where data, time and budget permit.

ACKNOWLEDGEMENTS

This study was financed by Environment Canada. The report was prepared by Cambridge Resources International Inc. under Formulation of Best Professional Practice for Incorporating Risk and Uncertainty into CBA Analysis of Environmental Regulations - Contract Number: 3000597037. The comments and suggestions of Mr. Alexandre Drzymala during the preparation of this paper are greatly appreciated.

Keywords: risk analysis, cost-benefit analysis, energy, nonrenewable resources, environment, Canada

JEL Classification: D61, D81, N52, N72, O13, Q42, Q51, Q53, Q58

Table of Contents

List of Tables

List of Figures

1. Literature Review of Risk and Uncertainty

Cost-benefit analysis (CBA) facilitates financial and socio-economic assessments of the effects of changes in regulatory policy. The primary objective of using CBA to evaluate a given regulatory-policy change is to determine its effect on national economic welfare and its distributional impacts across affected stakeholders.[2]

The first step in undertaking a CBA is to develop a spreadsheet model for the ex-ante evaluation. This model must identify all relevant technical, financial, economic and environmental data, along with assumptions regarding the estimation of costs and benefits. The data and assumptions used to begin the ex-ante calculation of costs and benefits are usually single value input estimates (i.e. mode or average, values).

However, the estimated ex-ante costs and benefits presented in cash/resource-flow statements are subject to a degree of uncertainty associated with data measurement, model and forecast errors.[3] These costs and benefits might involve large changes in the welfare of particular groups of individuals and/or the environment (Lemp and Kochelman, 2009; Zwikael and Ahn, 2011).[4] An analysis of risk and uncertainty must therefore form an integral part of any CBA, on a par with financial and economic analysis (Jenkins et al, 2011; Bock and Truck, 2011; Flyvberg, 2009).

Another possible source of error in the effort to capture the net welfare changes of an intervention is under- or over-prediction— a mistake decision-makers can avoid by addressing the following key questions:

1) What are the chances that the anticipated benefits and costs will be realized?

2) How does one choose between projects with different expected outcomes, as well as different levels of risk and uncertainty?[5]

---

[2] For regulatory proposals, the without/baseline situation will represent cash (resource) flow over time if the intervention is not implemented, with cash (resources) allocated according to market forces in the context of the existing, legally binding, regulatory environment.

[3] In project-appraisal terminology, the cash-flow statement is used in the financial analysis, and the resource-flow statement in the economic analysis. That is, a project owner is primarily concerned with the project's impact on his/her net wealth, as reflected by the financial NPV arising from net cash flows over time. The government is primarily concerned about the probability of an overall net economic benefit or its impact on the well-being of particular social groups, with all costs and benefits reflected in resource flows. Each of these groups is affected by different degrees of risk and uncertainty.

[4] Output, as calculated on the basis of deterministic input values, should also be reported. Deterministic values permit comparisons between the probabilistic analysis and past or screening-level risk assessments. Deterministic estimates may also be used to answer scenario-specific questions and to facilitate risk assessment. When comparisons are made between deterministic and probabilistic model outcomes, it is possible to explain similarities and differences in the underlying data, assumptions, and model.

[5] For an illustrative example and discussion, see, for example, Handbook of Cost-Benefit Analysis, Department of Finance and Administration, Commonwealth of Australia, January 2006, Chapter 6: Allowing Risk and Uncertainty, pages 70-71.

In a CBA base case, the direct costs and benefits to society of an intervention are estimated and assigned single-value or deterministic monetary values for each period, over the life of the intervention. These future values are then discounted to derive a net present value (NPV) for the intervention at a specified point in time. Each input variable used in the spreadsheet model is therefore expressed as a single value, assumed to have a 100% certainty of occurring.

Most interventions entail considerable risk and uncertainty. CBA is a useful means of establishing expected variability of net returns and the probability of a negative or positive outcome, as well as analyzing how this uncertainty may affect returns to key stakeholders (e.g. producers, consumers, etc.). The study should also identify the different forms of risk and uncertainty associated with the intervention, across time, types, and location of intervention (Asian Development Bank, ADB, 2002, p.72-75).[6]

a. Definitions of Risk and Uncertainty

The terms risk and uncertainty refer to perceptions about the occurrence of 'alternative' future events, in which current assumptions might not hold. However, the terms are not interchangeable. Risk exists when the potential event or outcome can be reasonably identified and estimated with a certain degree of confidence (e.g. annual rainfall, wind intensity, movements in relative prices). Uncertainty exists when the potential event or outcome cannot be reasonably identified, or the probability of an event occurring is unknown (e.g. tax changes, regulatory changes, technological change). Therefore, risk is the measurable variability of a parameter whose distribution of values can be defined, while uncertainty is variability whose distribution of values cannot be defined (Hillson and Murray-Webster, 2004).

Both risk and uncertainty impact on the variables defining an intervention, resulting in different outcome values for the cash- or resource-flow statements of an intervention compared to estimates based on the deterministic single value estimates. From the decision-maker's standpoint, assumptions regarding future risk fall into two broad categories, according to which variability can be ascribed either to an a priori probability or to a statistical probability. In contrast, decision-maker assumptions regarding future uncertainty can be ascribed either to subjective probability, in which the data to define a statistical probability are not available, or to socialization, in which the future is inherently unknowable and may bear little or no relation to the past or the present (see Table 1).[7]

[6] Examples of Risk Assessment for Transport, Energy and Environment projects are available at http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

[7] Uncertainty Category (1) is a natural extension of Risk Category (2). The main difference, however, is that the decision-maker faces a range of possible future events but without sufficient and reliable data to be able to assign probabilities to the variable. The probabilities assigned to input values are therefore less accurate, based on subjective assessments (i.e. personal opinion or a priori). That is, the decision-maker may rely only on "beliefs" or "expectations" to estimate the likelihood of various events or outcomes. Uncertainty Category (2) in which both the nature and range of future events are unknown and unknowable is an extreme situation, and one in which it is impossible to derive subjective or relative frequencies based on past observations.

Table 1. Assumptions about Decision-Maker Views on the Nature of the Future

Risk Category 1: A priori probability	The decision-maker's view is that they are able to assign objective probabilities to a known range of future events on the basis of mathematically 'known chances', e.g. the probability of throwing a six with a perfect die is 1 in 6.
Risk Category 2: Statistical Probability	The decision-maker's view is that they are able to assign objective probabilities to a known range of future events on the basis of empirical/statistical data about such events in the past, e.g. the probability of being involved in a building fire.
Uncertainty Category 1: Subjective Probability	The decision-maker's view is that they face a known range of possible future events, but lack the data necessary to assign objective probabilities to each. Instead, they use expectations grounded in historical practice to estimate the subjective probability of future events—akin to scenario planning, e.g. By how much will a new set of government regulations on driver education reduce the incidence of automotive accidents?
Uncertainty Category 2: Socialized	The decision-maker's view is that they face a situation in which the nature and range of future events is unknown, not simply hard to understand because of a lack of relevant data. The future is inherently unknowable, because it is socially constructed and may bear little or no relation to the past or the present. e.g. How will driverless automobiles change the nature of the transportation system?

Source: Sanderson, 2012, p.437

b. Techniques for Dealing with Risk and Uncertainty in the Appraisal of Public Interventions

The success of any type of risk and uncertainty analysis is dependent on the accuracy with which variables are identified, and the predictive ability of the spreadsheet model employed. However, the project analyst must strike a balance between the time and resources spent on the analysis of risk and uncertainty, and the degree of greater accuracy likely to be realized. In other words, a great deal of time and effort should not be lavished on improving the accuracy of variables that will have only a small impact on intervention outcomes. Rather, the focus should be on those variables expected to have a large impact on outcomes—that is, on the net present values to the economy and other key stakeholders.[8] Two of the most basic tools for assessing risk and uncertainty are sensitivity analysis and simulation-based risk analysis.[9] These two basic categories of tools encompass break-even analysis (switching values), decision-tree analysis, and scenario analysis.

Sensitivity Analysis

Sensitivity analysis is a useful preliminary tool with which to determine the variability of project outcomes. It is less useful, however, in assessing the effectiveness of actions to mitigate those risks.

Before attempting sensitivity analysis, the project analyst must construct a spreadsheet model of project inflows and outflows. The first step is to build a financial/economic/stakeholder cash-flow model of the intervention, using single estimates or assumptions about input values. This will produce a set of single value estimates of the key outputs of analysis.

In the context of assessing the impact of regulatory change, a set of estimated outputs could include the health and environmental effects of certain variables on the net present values of specific stakeholders, such as private sector interests, the economy, and perhaps the government budget.

The next step is to carry out sensitivity analysis, by altering either the values of key input variables or the assumptions that underpin estimated costs and benefits. This process is repeated for each of the input variables expected to have some impact on outcomes. The change in projected key outputs is then recorded, according to the change in the value of the input variable.

Break-even analysis is a useful form of sensitivity analysis, in which the analyst identifies the value of a particular variable required for an intervention to achieve a specific result or target.

[8] The project analyst must define all terms used in the model calculations, provide complete references for all data, justify assumptions, and show all formulas applied in the estimation of stakeholder impacts. The analyst must also acknowledge the model's limitations.

[9] Deterministic spreadsheet models can be easily converted into either a probabilistic model, for scenario analysis, or a simulation-based risk analysis. Both are widely used (Fao and Howard, 2006; Kwak and Ingall, 2007; European Commission, EU, 2014; HM, Green Book, UK, 2015).

Monte Carlo Simulation

Simulation-based risk analysis, known as Monte Carlo analysis, is a form of sensitivity analysis in which outcomes are calculated using input values based on probability-weighted distributions. The technique simulates a large number of draws from the given distributions of input variables in order to establish the resulting distributions of outcomes.

A Monte Carlo simulation can only provide a realistic distribution of outcomes if the assumptions and data underpinning the analysis are realistic and accurate, and if the model correctly captures intervention's costs and benefits.[10]

Simulation-based risk analysis must employ input data distributions that are carefully selected and clearly presented. The accuracy of the model's outcomes depends on the accuracy of the probability distribution of risk variables.

Scenario Analysis

Scenario analysis is another means of comparing a base case, or average expectation, with one or more other scenarios. These may include a best case (or optimistic case), in which the discounted net resource flows will be better than base-case expectations, and a worst case (or pessimistic case), in which discounted resource flows will be worse than base-case expectations. The optimistic and pessimistic scenarios are defined by extreme (lower and upper) values for each variable, selected from within a realistic range. The main advantage of the scenario-analysis model is that it allows relationships between different project variables to be explored–of particular help, for example, when evaluating alternative policy options or regulatory proposals for government intervention.[11]

c. International Practice of Risk Analysis

Decision-makers in most advanced economies employ ex-ante cost-benefit analysis to aid in the design and implementation of regulatory measures. However, approaches to the challenge of incorporating risk into an evaluation of costs and benefits differ. The following section offers an overview of current practice in five leaders in the application of CBA, namely, the United Kingdom, Australia, the European Union, France, and the United States.[12]

---

[10] For more information, see for example Clarke and Low (1993), Savvides (1994), Vaughan et al. (2000), and Bock and Truck (2011), and Clarke (2014).

[11] For more information, see for example Mietzner and Reger (2005).

[12] Also, see New Zealand, The Treasury. Guide to Social Cost Benefit Analysis. 2015. Issues in Cost Benefit Analysis, p.50-51 & Appendix 1: Monte Carlo Simulation, p.60-61.

The United Kingdom

The UK Government suggests the use of expected value (EV) or decision trees to assess project risk, and sensitivity analysis, scenario analysis, or Monte Carlo simulations to evaluate project uncertainty (UK, Green Book, 2015).

The assessment of risk using EV entails the calculation of a probability-weighted estimate of a specified set of intervention outcomes. This is established by multiplying alternative possible outcomes (e.g. NPVs) by their probability of occurring, where the sum of the resulting products is the expected value (i.e. expected NPV). However, this method only applies where both likelihoods and outcomes can be reasonably estimated.

Alternatively, the decision-tree technique entails the calculation of total expected value from the probabilities of particular events (e.g. likelihood of changes in traffic volume), the occurrence of which depend on other events (e.g. probability of movements in oil price). Decision-tree analysis thereby enables the analyst to consider a chain of multiple options.

To understand the impacts of uncertainty on the outcomes of a regulatory intervention, the UK guidelines recommend beginning with sensitivity analysis. To that end, the outcome of the CBA analysis is re-calculated one parameter at a time, on the basis of a series of 'what if' questions. Each combination of inputs thus yields an outcome representing a project scenario. A more encompassing scenario analysis is recommended for large, complex interventions, creating detailed models of possible future states following major policies changes.

Where a number of variables are associated with significant uncertainties, the use of a Monte Carlo simulation is recommended in order to assess their collective impact. In such a case, the probability distributions of the uncertain variables are hypothetical, as are the correlation parameters describing the interaction of the uncertain input variables. The outputs of the Monte-Carlo simulation yield the expected values for the outcome variables, as well as the probability distributions of these outcomes, consistent with the set of hypothetical distributions and the correlation parameters between input variables.

Australia

The Commonwealth of Australia's project assessment framework generally recommends that both sensitivity and scenario analysis be conducted to assess the impact of risk and uncertainty on the costs and benefits of regulatory interventions. In cases where there are a large number of variables subject to a significant degree of variability, a full risk analysis (Monte Carlo simulation) is recommended, in order to capture the combined effects of risks and uncertainties associated with the intervention.

According to the assessment framework, sensitivity analysis should be carried out by re-estimating outcomes of the regulatory change (e.g. NPV) for plausible values for each of the important input variables, individually and simultaneously. Scenario analysis is also recommended, on the basis of a) optimistic and b) pessimistic scenarios. Both should have a realistic and reasonable likelihood of occurrence. If the re-calculated project NPV is positive for the pessimistic case, further sensitivity analysis is not recommended. However, if the project NPV for the pessimistic case is negative, further sensitivity analysis is suggested.

Depending on the direction of correlation, variables should be allowed to move together in a two-way sensitivity analysis, in the same or opposite directions. If a number of input variables suffer from variability and are correlated, the next step is to conduct a Monte Carlo simulation. This allows the analyst to incorporate probabilistic distributions of many uncertain variables used in the CBA, and to re-evaluate the effects of simultaneously changing various assumptions, on both the expected outcomes of the intervention and their probabilistic distributions.

European Union

After many years of practicing cost-benefit analysis, in 2014 the European Union issued updated CBA guidelines that include a framework for the systematic treatment of risk and uncertainty (EU, 2014), providing a practical approach that combines quantitative and qualitative forms of analysis.

The recommended quantitative analysis is primarily based on sensitivity and scenario analysis. Under the framework, sensitivity analysis is used to highlight sensitive variables, with an emphasis on identifying variables' switching values—the point at which the NPV of a given regulatory proposal is negative or below a minimum acceptable level. For complex interventions in which a significant number of variables are subject to risk, a Monte Carlo simulation is recommended.

The recommended qualitative analysis involves the preparation of a list of all adverse events to which the intervention may be subject, along with a risk matrix for each including cause of the event, link to sensitivity analysis, negative effects, ranked levels of probabilities of occurrence, and measures of risk mitigation.

France

The French Government recommends the use of sensitivity analysis and scenario analysis to integrate risk and uncertainty into cost benefit analysis (Gollier et al. 2011). However, a full risk analysis using Monte Carlo simulation is recommended where a number of key input variables are subject to risk and uncertainty.[13]

United States

The US Government recommends that an evaluation of the impacts of risk and uncertainty on proposed regulatory changes begin with sensitivity analysis, usually followed by a full risk analysis (Monte Carlo simulation).

[13] The importance of a full risk analysis is discussed in Gollier et al. (2011, p.21-44).

Sensitivity analysis enables the analyst to identify variables critical to the assessment, management, and communication of risk. As in Australia, US guidelines suggest that if a deterministic cost-benefit model generates acceptable outcomes under pessimistic assumptions, then sensitivity analysis may be deemed to provide sufficient screening for risk. In such cases the use of additional, probabilistic methods would not be considered necessary. In most cases, however, Monte Carlo simulations would be required, providing a full risk analysis of the costs and benefits of regulatory interventions, including the effect of specific decisions or mitigating measures on outcomes both in terms of expected values and the probabilities of achieving specific outcomes.

d. Examples of High Quality Risk and Uncertainty Analysis in CBA: Applications to Regulatory Impact Analysis of Environmental Regulations

The USA Environmental Protection Agency (EPA) is a world leader in the integration of risk and uncertainty in cost-benefit analysis of the regulatory impact of environmental regulations. A series of 16 such assessments, published in 2014, offer invaluable insight into the EPA's approach, along with extensive supporting material (see footnote 13 for web links).[14,15]

2. Review of the Canadian Approach to Risk and Uncertainty

The Canadian Cost-Benefit Analysis Guide: Regulatory Proposals, issued by the Treasury Board Secretariat of Canada in 2010, provides limited guidance on the analysis of variability of outcomes due to risk and uncertainty in the cost-benefit analysis of regulatory interventions.

The Guide recommends the use of sensitivity analysis to identify the important assumptions upon which CBA is based—that is, those assumptions to which outcomes are most sensitive. However, sensitivity analysis does not assign probabilities to possible outcomes, nor can it establish the correlations between specific variables that may have an important effect on the evaluation of outcomes. Furthermore, the base scenario used in such an analysis is rarely built around mean values.

---

[14] US Environmental Protection Agency (EPA) (2014) probabilistic risk assessment case studies can be found at: http://www.epa.gov/sites/production/files/2014-12/documents/raf-pra-white-paper-final.pdf. See also US Environmental Protection Agency (EPA) (2014) Probabilistic Risk Assessment to Inform Decision Making: Frequently Asked Questions. EPA/100/R-09/001B. Washington, D.C.: Risk Assessment Forum, Office of the Science Advisor, USEPA. http://epa.gov/raf/prawhitepaper/index.htm.

[15] See also sectoral risk assessments presented in European Commission, EU (2014), including for transport (chapter 3), the environment (chapter 4), and energy (chapter 5). For types of risks and risk assessment in project appraisal for sectors including agriculture, education, health, electricity transmission, and renewable energy, see chapter 5 and Appendix 3 of guidelines prepared by the Asian Development Bank (2002).

A more accurate estimate of the value of expected outcomes is provided by Monte Carlo analysis, which is based on the full distribution of possible values of highly variable parameters, and is therefore recommended as a natural extension of sensitivity analysis. A Monte Carlo simulation is also helpful in interpreting the ranges of key outcomes resulting from a regulatory intervention, as results of the analysis are expressed in terms of the expected outcome and the probabilities of key outcomes occurring.

3. Recommendations on Best Practices to Use at Environment Canada when Developing CBA

a. Summary of Recommendations to Address Risk and Uncertainty in CBA

The recommended framework for the development of a cost-benefit analysis of an environmental regulatory intervention can be broken down into 8 steps, as summarized in Table 2.

A prerequisite for the quantitative assessment of risk and uncertainty is a complete and consistent spreadsheet model, detailing the relationships between anticipated incremental flows of costs and benefits over time. That is, the evaluation of the risk and uncertainty of key variables depends on their accurate identification, and on the technical accuracy of their incorporation into the basic analytical model. More specifically, the model must accurately define:

1) the financial relationships between variables; and

2) the costs and benefits of economic resources, measured according to a consistent application of the principles of applied welfare economics.

The method by which variables are assessed depends on the availability of data, time, and budgetary resources, as well as the qualitative and quantitative statements required of said variables. The framework presented here focuses on the development of a spreadsheet model using sensitivity analysis, scenario analysis, and Monte Carlo simulation, and the interpretation of the resulting output distributions in decision-making. A key benefit of the suggested approach is that it provides inputs critical to the design of a regulatory program by facilitating the evaluation of possible actions to mitigate the cost of risk and uncertainty.

Table 2. Components of an Analysis of Risk and Uncertainty

Steps	Task	Procedures
1	**Assess Risk and Uncertainty**	1.1 Identify risk and uncertainty inherent in the options analyzed. Undertake a sensitivity analysis to establish which variables have a significant effect on outcomes (e.g. financial NPV, economic NPV, on consumers, on specific stakeholders).
2		1.2 For variables subject to risk, quantify range and distribution, including possible end-points. If appropriate, assign correlation coefficients between variables. The distributions and correlations can be based on either historical experiences or expert opinion.
3		1.3 For variables subject to uncertainty, determine a central point (expected value) and, if possible, maximum and minimum values.
4		1.4 Risk (and uncertainty) analysis: quantify the impacts of risky variables on the feasibility and ranking of alternative regulatory measures (<u>use of Monte Carlo simulations</u>).
5		1.5 Consider mitigating measures that would reduce the potential costs of risk by providing for alternative ways of achieving desired goals in the design of the regulatory intervention. Greater flexibility in the face of uncertainty may produce a more satisfactory result (e.g. How does a result change if amendment changes"?).
6	**Assess Overall Results of Analysis**	1.6 Analyze and provide feedback on overall results, including NPVs, distributional impacts, risk and uncertainty analysis, and options for risk mitigation.
7		1.7 Highlight impacts that cannot be assigned a monetary value, and any important concerns.
8		1.8 Present findings and final recommendations.

<u>Source</u>: Authors' own elaboration.

b. Application of Risk and Uncertainty Assessment to Proposed Renewable Fuel Regulation

Preliminary Assessment of Potential Regulatory Proposal

Introduction

The Government of Canada (GoC) has demonstrated its commitment to reducing greenhouse gas emissions through the increased production and use of renewable energy sources (RES), such as ethanol and biodiesel. (See Table 3 for a summary of the rise in Canada's GHG emissions by sector from 1990 to 2010.)
GoC Regulations Amending the Renewable Fuels Regulations, published in 2006, required an average renewable fuel content by volume of 5% for gasoline by 2010. By the time the Renewable Fuels Regulations were officially published in the Canada Gazette in 2010, an additional provision required an average renewable fuel content by volume of 2% for diesel and heating distillate oil by 2012.

Table 3. GHG Emissions Inventory by Economic Sector in Canada (Mt CO2e)

Sector/Year	**1990**	**1995**	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Transportation	**129.4**	**137.5**	**155.9**	**170.6**	**170.6**	**173.2**	**171.4**	**167.9**	**172.5**
Buildings	**73.3**	**79**	**85.1**	**85.4**	**80.4**	**85.9**	**85.4**	**83.5**	**80.5**
Electricity	94.7	98.2	128.8	117.8	112.1	117.7	108.6	94	95
Oil and Gas	107.2	132.9	158.6	159.4	163	167.8	161.7	160	162.1
Emissions-intensive and trade-exposed industries	95.5	98.3	92.1	88.2	88.4	87.5	85.7	72.1	74.5
Agriculture	56.5	64.6	68.5	70.2	69	70.3	70.9	66.7	67.9
Waste and others	56.3	55	55.3	55.9	54.7	56	55.5	52.1	53.8
National GHG Total	**612.9**	**665.5**	**744.3**	**747.5**	**738.2**	**758.4**	**739.2**	**696.3**	**706.3**

Source: Environment and Climate Change Canada, April 2016, www.ec.gc.ca

The GoC's Renewable Fuels Strategy Regulation aimed to achieve four policy objectives:

1) reduce GHG emissions resulting from fuel use;

2) encourage greater production of renewable fuels;

3) provide new market opportunities for agricultural producers and rural communities; and

4) accelerate the commercialization of new renewable fuel technologies.

From a cost-benefit perspective, however, this intervention raises two key questions. First, these regulatory measures were the only ones considered to achieve stated policy objectives. Second, the published regulations did not specify the type of renewable fuel to be used.

Regulatory Scenario and Impact Assessment

The renewable energy sources considered here are biodiesel (produced from soybeans, tallow, and canola) and hydrotreated vegetable oil (HVO, in the form of palm oil). Kerosene is sometimes added to biodiesel blends to improve the cloud point in winter temperatures. However, if HVO is blended in heating oil, the addition of kerosene is not required.

Three alternative scenarios can therefore be developed regarding the use of kerosene to meet the requirements of the amendment namely:

Scenario I (central scenario): "with" kerosene—used in diesel and heating oil

Scenario II: "without" kerosene—not used in diesel or heating oil

Scenario III: "without" kerosene—used in heating oil only

Kerosene volumes are thus established as the choice variable in this study, with incremental costs and benefits measured under each scenario in terms of the difference between "with" and "without" regulation.

Incremental costs and benefits under each scenario were initially estimated on a regional basis then added together to reach an estimate of their overall economic impact. From an accounting perspective, the analysis includes the benefits and costs to Canada plus the worldwide benefits of CO2 reduction, evaluated as the global social cost of carbon. The incremental impacts of the proposed regulation were evaluated over 25 years beginning from 2011, when the amendment was expected to come into force in the West, the East, and Ontario.[16] The projected rate of growth in demand for fuel subject to blending is 1.7 percent per year over the study period. Impacts are estimated in monetary terms to the extent possible, expressed in 2007 Canadian dollars (C$) using a real discount rate of 3% for all benefits and costs.[17] A discount rate of 8 percent is used in the sensitivity analysis.

---

[16] The regions are defined as the "West," which includes British Columbia, Alberta, Saskatchewan and Manitoba; the "East," which includes Quebec, New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador; and "Ontario."

[17] Foreign exchange transactions are converted to C$ equivalent, based on the average historical exchange rate. The real exchange rate between US$/C$ is assumed to be constant over the lifetime of the proposed regulation. Hence, potential impacts of a fluctuating exchange rate are not presented in this model. Similarly,

The main costs of the regulation are variable, in the form of the production and import of renewable and non-renewable energy sources. These variable costs are calculated for the production and import of renewable energy sources needed to meet the requirements of the regulatory amendment, given projected demand for diesel and heating oil. These costs are modified and re-calculated according to scenario. The fixed incremental capital costs incurred by fuel producers for terminal upgrades and the fixed capital costs incurred by station owners for retail outlets are included in industry costs. Finally, the additional cost to consumers due to the low energy content of kerosene is included in consumer costs. Similarly, environmental costs increase as emissions rise due to the consumption of greater volumes of less efficient fuel.

The main economic benefits of the Amendment come directly from savings in diesel and heating oil displaced by renewable fuel content. The economic benefits of the proposed regulation are estimated and expressed in terms of the monetary values of incremental energy savings from the avoided costs of diesel fuel and heating oil purchases. The benefits of reduced GHG emissions are calculated on the basis of a social cost of carbon of $25/ton and included as an economic benefit. Table 4 summarizes the incremental costs and benefits of a 2% renewable fuel requirement under each scenario, and estimates the impacts of the amendment on various stakeholders, including costs to biodiesel producers, fuel producers, importers, retail outlets, and consumers.

Overall, the Amendment is expected to result in a net economic cost over 25 years under each scenario: $2.4 billion under scenario I; $1.6 billion under scenario II; and $2.2 billion under scenario III (see Table 4, row E). Expressed in terms of cents/liter of fuel, the economic costs under each scenario are 0.26, 0.18 and 0.24 cents/liter, respectively (see Table 4, row F).

However, the Amendment will result in a cumulative reduction in CO_2 emissions over the 25-year period under scenarios I, II, and III, of 22.4 Mt, 23.6 Mt and 20.1 Mt, respectively (see Table 4, row H). Expressed on an annual average basis, these reductions are equivalent to around 0.90, 0.94, and 0.84 Mt CO_2 under scenarios I, II, and III, respectively (see Table 4, row I).

Reductions in GHG emissions from diesel and heating oil following implementation of the Amendment are estimated over 25 years (see Table 4, row H (a) and H (b)). The result is a cumulative reduction in CO_2 emissions for the transport sector of between 17.6 Mt (scenarios I and III) and 18.6 Mt (scenario II), and of between 2.5 Mt (scenario III) and 5 Mt (scenarios I and II) for the heating of buildings.
A comparison of annualized emission levels for 2010 (reported in Table 3) reveals an annual decrease in total emissions for the transport sector under scenarios I, II, and III equivalent to 0.41, 0.43, and 0.41 percent of 2010 levels, respectively (see Table 4, row L). Similarly, we find that implementation of the Amendment will result in a decrease of 2010 GHG emissions for buildings under all three scenarios, with annual average falls of 0.24, 0.25 and 0.13 percent, respectively (see Table 4, row M).

---

the analysis is based on real values at 2010 prices, so the impact of inflation on market exchange rates and market nominal prices are not reflected in this analysis.

Table 4. Incremental Cost-Benefit Statement of Amendment, by Scenario, 2011-35 (PV in $M – 2007, at 3% real rate of discount)

Incremental Costs and Benefits ($M)	**(I) "With"—Kerosene Used in Diesel and Heating Oil**	**(II) "Without"—Kerosene Not Used in Diesel or Heating Oil**	**(III) "Without"— Kerosene Used in Heating Oil Only**
INCREMENTAL COSTS			
A. Quantified Industry Costs			
Cost to Biofuel Producers			
Cost of Producing Biodiesel	4,693	4,693	3,696
Sub-Total	4,693	4,693	3,696
Cost to Fuel Producers & Importers			
Capital Costs	157.2	157.2	157.2
Operation & Maintenance Costs	112.4	112.4	112.4
Cost of Imports of Biodiesel	12.2	12.2	10.2
Cost of Imports of HVO	775	775	1,893
Cost of Imports of Kerosene	6,408	0.0	5,371
Biodiesel Transportation Costs	1934	194	152
Administrative Costs	7.1	7.1	7.1
Sub-Total	7,665	1,257	7,704
Cost to Upgrade Retail Outlets			
Capital Costs	3.1	3.1	3.1
Sub-Total	3.1	3.1	3.1
Total Industry Costs	12,361	5,953	11,403
B. Quantified Consumer Costs			
Additional Blended Diesel and Heating Oil Purchases	203	0	175
Total Consumer Costs	203	0	175
Total Costs	**12,563**	**5,953**	**11,577**
INCREMENTAL BENEFITS			
C. Quantified Energy Saving Benefits			

Incremental Costs and Benefits ($M)	(I) "With"—Kerosene Used in Diesel and Heating Oil	(II) "Without"—Kerosene Not Used in Diesel or Heating Oil	(III) "Without"— Kerosene Used in Heating Oil Only
Avoided Cost of Purchasing Diesel/Heating oil	9,725	3,858	8,939
D. Quantified Environmental Impacts			
Benefits of GHG Emission Reductions, estimated at Social Cost of Carbon of $25/ton	470.3	494.8	443.1
Total benefits[18]	10,196	4,353	9,382
E. Net Economic Benefits (C+D)-(A+B)	**-2,368**	**-1,600**	**-2,195**
F. Total Liters of Heating and Diesel Oil (ML)	**906,377**	**906,377**	**906,377**
G. Average Cost (cents per liter of fuel demand) [Row G= Row E/Row F	**0.26**	**0.18**	**0.24**
H. Total Reduction in GHG Emissions (Mt CO2e) (2011-2035)	**22.41**	**23.58**	**20.12**
a. of which from Diesel Oil Demand (2011-35)	17.6	18.61	17.6
b. of which from Heating Oil Demand (2011-35)	4.79	4.98	2.50
I. Annual Average Reductions in GHG Emissions (Mt CO2e) [Row K = Row H/25 years]	0.90	0.94	0.84
J. GHG Emissions by Transportation (2010)	172.5	172.5	172.5
K. GHG Emissions by Buildings (2010)	80.5	80.5	80.5
L. Annual Average Emission Reductions in Diesel Oil – compared to 2010 (%) [Row L = Row H(a)/Row J	0.41%	0.44%	0.41%
M. Annual Average Emission Reductions in Heating Oil – compared to 2010 (%) [Row M = Row H(b)/Row K	0.24%	0.25%	0.13%

Source: Authors' calculations

[18] For the non-monetized qualitative impacts on the Canadian economy, see Canada Gazette (July 20, 2011), 145:15, *Table 14: Incremental Cost-Benefit Statement,* available at http://canadagazette.gc.ca/rp-pr/p2/2011/2011-07-20/html/sor-dors143-eng.html

Identification and Assessment of Potential Sources of Variability

Sensitivity and Risk/Uncertainty Analysis

A risk variable is one that has a significant impact on outcomes, and the value of which varies. The following section identifies key risk variables in the context of the Government of Canada's proposed Regulations Amending the Renewable Fuels Regulations ("the Amendment"). Figures 1 and 2, presenting components of the economic costs and benefits resulting from the Amendment, are based on deterministic results.

Under the central scenario (scenario I), the incremental costs of producing biodiesel and of importing kerosene respectively account for 51% and 37% of total incremental costs resulting from the regulatory change. Under scenario II, the production of biodiesel accounts for 79% of incremental costs, with a further 13% from additional HVO imports. Under scenario III, incremental costs are accounted for by kerosene (46%) biodiesel (32%), and additional HVO imports (16%–see Figure 1). Variations in the price of kerosene and biodiesel will therefore have a significant impact on scenario outcomes, and are thus key risk variables.

Avoided expenditure on diesel and heating oil is the main benefit of the proposed Amendment, accounting for 90 to 95% of total benefits under all three scenarios (see Figure 2). The value of such savings will depend on the volume and price of diesel and heating oil displaced by renewable content, whereby an increase in the price/volume of diesel and heating oil not purchased will improve the overall economic benefit of the Amendment. Variations in the price of diesel and heating oil will therefore have a significant impact on scenario outcomes, and are thus key risk variables.

Because diesel oil, heating oil, and kerosene are all products of crude oil, their prices move together (Li, 2010, p.460; Borenstein et al., 1997; Natural Resources Canada, 2011, p.25).[19] In addition, petroleum products are deregulated in Canada, further supporting this causality between crude oil and refinery product prices.[20] However, the precise impact of the crude oil price on the price of each fuel is different, because the cost of crude oil as a share of wholesale production costs varies from one to the other (Natural Resources Canada, 2006, p.7; Natural Resources Canada, 2011, p.26; Natural Resources Canada, 2014-2015, p.34).

The cost of crude oil on average accounts for 47% of the retail price of diesel oil (excluding taxes), 57% of heating oil, and 54% of kerosene. Hence, the crude oil price is

[19]Full reports are available at: http://publications.gc.ca/collections/collection_2015/rncan-nrcan/M12-19-2006-1-eng.pdf; http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/eneene/sources/crubru/revrev/pdf/revrev-09-eng.pdf, and http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/2014/14-0173EnergyMarketFacts_e.pdf

[20] The real exchange rate between US$/C$ is assumed to be constant throughout the lifetime of the proposed regulation. See also Figure 1.1 compiled by Energy Board of Canada, available at https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/2013/index-eng.html

the key risk factor affecting the price of these petroleum products.[21] In the deterministic analysis, prices of refinery fuels are calculated to be consistent with a long-run real average crude oil price of $49.45/barrel—the long-run average real price for the period 1974 to 2015.

Biodiesel is a renewable fuel source produced from feedstock such as soybeans, canola, and tallow, the price of which is affected by that of its substitute, diesel.[22] The prices of biodiesel (cost input) and diesel (benefit input) are highly positively correlated, with a coefficient of about 0.90 (e.g. Coyle, 2013; Pokrivcak and Rajcaniova, 2011; Tareen et al., 2000).

In order to improve the cloud point of biodiesel in winter temperatures, kerosene is added to blends. However, the lower energy content of kerosene relative to diesel or heating oil results in a significant reduction in the benefits of biodiesel compared to these fuels. Under scenarios I and III, the addition of kerosene accounts for about 50% of total costs. An increase in the price of crude oil (and so kerosene) therefore reduces the profitability of these scenarios as compared to scenario II, in which no kerosene is used. In other words, the price of kerosene is a risk variable under scenarios I and III, but not scenario II.

The environmental benefits of the Amendment are calculated on the basis of emission savings from the replacement of fossil fuel, and the social cost of carbon (SCC). The benefits of improving environmental quality (reduction in emissions multiplied by SCC) account for 5-10% of total economic benefits of the intervention under all three scenarios. It must be noted, however, that SCC is subject to a very high level of uncertainty, with estimates ranging from -$10 to 100/per ton of CO_2. The distribution used in this analysis is based on expert opinion (Greenstone et al, 2011).

Under the analysis presented here, the amount of renewable fuel required is set at 2 percent of total projected demand for diesel and heating oil, with volumes of biodiesel, kerosene, and HVO calculated as proportions of this requirement. Demand for biodiesel, kerosene, and HVO will depend on demand for diesel/heating oil. Similarly, overall benefits are subject to future energy demand, forecasts for which are subject to uncertainty.

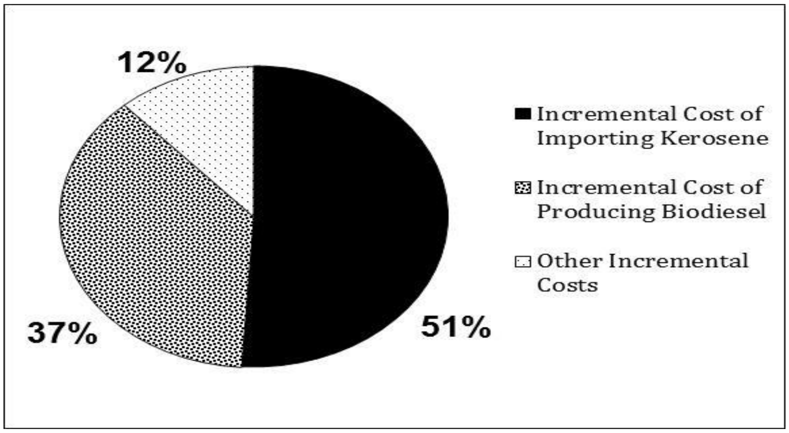
An assessment of intervention costs and benefits reveals four potentially major sources of variability: real crude oil prices, real prices of domestic biodiesel, the social cost of carbon, and changes in demand for diesel and heating oil. The rationale underlying the selection of these four factors is summarized in Table 5.

[21] Fuel retail prices exclude federal and provincial taxes, but Canadian consumers are price-responsive to tax-inclusive retail prices.

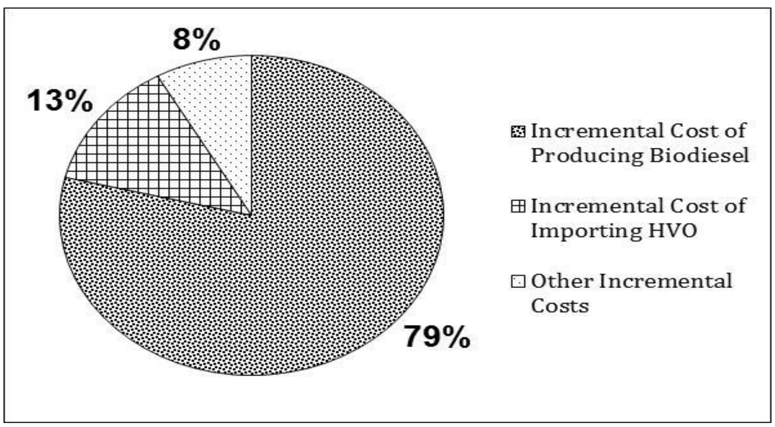
[22] The distribution of feedstocks for the production of Canadian biodiesel is provided in Table 5 of Canadian Gazette, July 2011, 145:15. The energy-content ratio of biodiesel to diesel is reported as 1, however the energy content of biodiesel is in fact higher. Hence, an increase in the price of diesel will increase the competitiveness of biodiesel fuel. This will have an impact on the net economic benefits; Canadian farmers will also benefit from an increase in demand for biodiesel fuel.

Figure 1. Shares of Incremental Costs of Amendment by Scenario, 2011-35 ($M, 2007)

a. "With"–Kerosene Used in Both Diesel and Heating Oil (Central/Scenario I)



b. "Without"—Kerosene Not Used in Diesel or Heating Oil (Scenario II)



c. "Without"—Kerosene Used in Heating Oil Only (Scenario III)

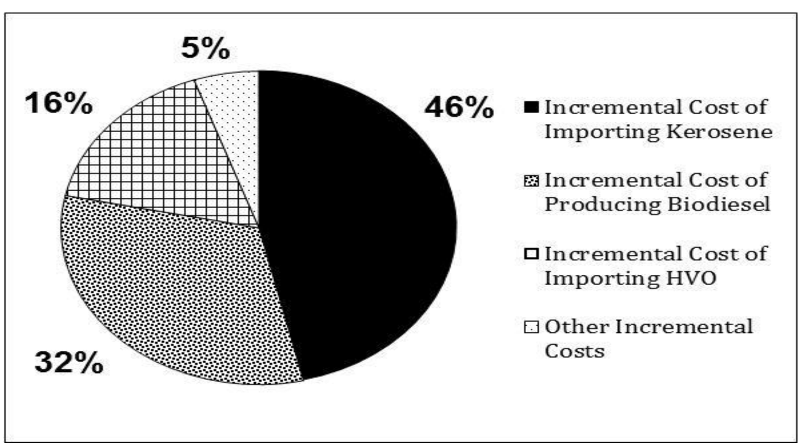
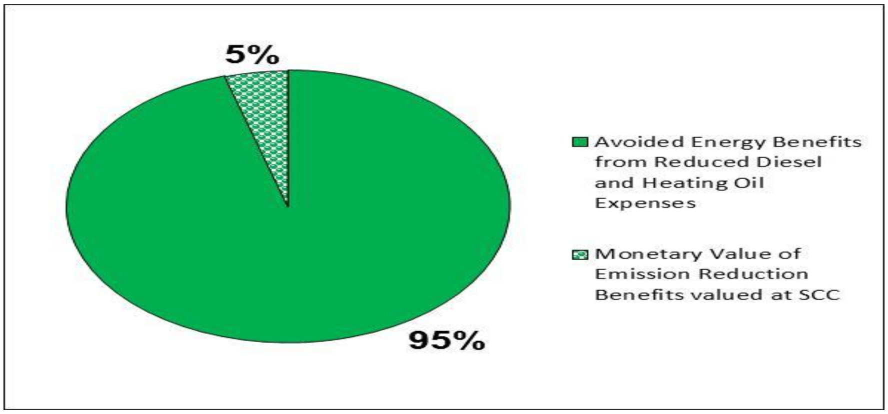
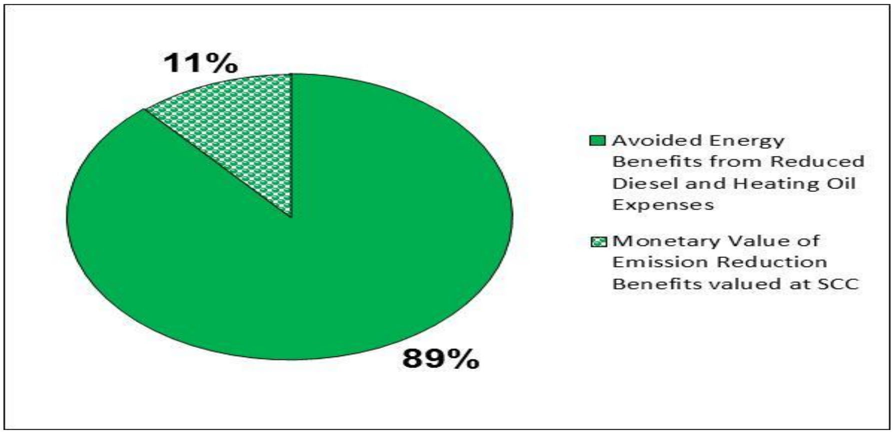


Figure 2. Shares of Incremental Benefits of Amendment by Scenario, 2011-35 ($M, 2007)

a. "With"—Kerosene Used in Both Diesel and Heating Oil (Central/Scenario I)



b. "Without"—Kerosene Not Used in Diesel or Heating Oil (Scenario II)



c. "Without"—Kerosene Used in Heating Oil Only (Scenario III)

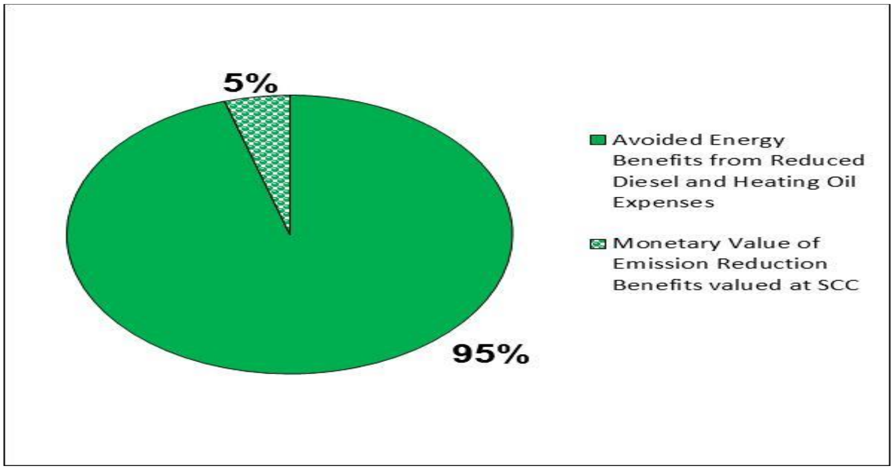


Table 5. Summary of Significant Market Risks/Uncertain Factors and Their Impact

Risk/Uncertain Variable	Impact and risk significance
Real Crude Oil Price ($/barrel)[23]	A market risk variable that impacts on both input costs and benefits. An increase in the price of crude oil will result in an increase in input costs of kerosene and biodiesel. Similarly, a higher than expected increase in the price of crude oil will increase prices of diesel and heating oil, boosting the energy savings that make up 90-95% of economic benefits of the Amendment, under all scenarios.
Real Price of Domestic Biodiesel Production ($/liter)	A market risk and cost variable. At 30-40% of total costs, this is the second-largest cost item under scenarios I and III, rising to 80% under scenario II.
Social Cost of Carbon ($/T)	This is an uncertain variable, with an assumed range of -$10/T to +$100/T.
Variation in Diesel/Heating Oil Demand	This is an uncertain variable. Diesel accounts for an average 89% of total demand and heating oil for the remaining 11%. Errors in demand forecasts will affect expected emissions levels when demand risk to fuel projections is incorporated in simulations.
Demand for Kerosene for use in Diesel and Heating Oil	Quantities of fuel sources used (costs) and displaced (benefits) are calculated on the basis of demand for kerosene, for use in diesel and heating oil. Because the use of kerosene is determined by regulatory policy, a probability distribution **cannot** be assigned to this parameter, and separate risk simulations are carried out for each scenario.

Rationale for and Assessment of Methodological Choice for Addressing Risk and Uncertainty

After defining those variables most likely to have a major impact on outcomes, sensitivity analysis is conducted to test their expected impact on the variability of outcomes. First, the impact of changes in the real price of crude oil price on net benefits and average cost per liter of fuel are tested under each scenario, at a real discount rate of 3% (see Table 6). These results are supplemented by a two-way sensitivity analysis between prices of crude

[23] Prices of diesel, heating oil, and kerosene are calculated based on $/liter conversion and the cost-share of crude oil in their production.

oil over the period, and deviations from projected base-case growth in demand for diesel/heating oil (see Table 7).
The results presented in Table 6 indicate that an increase in the price of crude oil will have the greatest impact under scenario II, followed by scenario I, and scenario III. This variation in impact across scenarios is explained by the relative differences in cost inputs used and volumes of inputs (diesel and heating oil) saved.

Table 6. Overall Impact of Real Crude Oil Price on Net Economic Benefits ($M) and Average Costs (cents/liter of diesel and heating fuel)[24]

Crude Oil Price $/Barrel	**%[25]**	**Impact under Scenario I $M**	**cents/liter**	**Impact under Scenario II $M**	**cents/liter**	**Impact under Scenario III $ M**	**cents/liter**
34.6	**-30%**	-3,074	0.34	-2,525	0.28	-2,649	0.29
39.6	**-20%**	-2,839	0.31	-2,217	0.24	-2,497	0.28
44.5	**-10%**	-2,603	0.29	-1,909	0.21	-2,346	0.26
49.5	**--**	**-2,368**	**0.26**	**-1,600**	**0.18**	**-2,195**	**0.24**
54.4	**10%**	-2,133	0.24	-1,292	0.14	-2,044	0.23
59.3	**20%**	-1,897	0.21	-984	0.11	-1,893	0.21
64.3	**30%**	-1,662	0.18	-675	0.07	-1,742	0.19

Source: Authors' calculations.

The two-way sensitivity analysis indicates the combined impact on a specific outcome when changing two variables at a time. As shown in Table 7, the economic benefits of the Amendment requiring a 2% renewable-fuel content are greatest when crude oil prices are high and demand for diesel and heating oil is low, under all scenarios. Net economic benefits are negative, because the costs incurred in achieving the 2% target are greater than the benefits gained from the displacement of diesel and heating oil demand. However, a higher real price of crude oil combined with lower projected demand will improve the relative strength of scenario II, due to its lesser need for crude oil inputs.

[24] The price of kerosene (input cost for economic costs), and of diesel and heating oil (input benefit for economic benefits), is linked to the price of crude oil.
[25] Percent-change impacts are calculated based on deviations from the base-case long-run average crude oil price of $49.45/barrel.

Table 7. Two-Way Sensitivity Test between Real Price of Crude Oil and Demand for Diesel and Heating Oil – Impacts on the Net Economic Benefits ($ M)

a. "With"–Kerosene Used in Both Diesel and Heating Oil (Central/Scenario I)

		Change in Average Real Price of Crude Oil (Base Case = 1.00 = $49.45/Barrel)								
Variation Factor in Demand for Diesel and Heating Oil (Base Case = 1.00)	**-2,368**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**	**1.05**	**1.10**	**1.15**	**1.20**
	0.88	-2,819	-2,508	-2,196	-1,885	-1,574	-1,263	-952	-641	-330
	0.91	-241	-52	138	327	517	706	896	1,085	1,275
	0.94	-1,191	-1,077	-964	-850	-736	-623	-509	-396	-282
	0.97	-2,007	-1,913	-1,819	-1,725	-1,631	-1,537	-1,443	-1,349	-1,256
	1.00	-2,839	-2,721	-2,603	-2,486	**-2,368**	-2,250	-2,133	-2,015	-1,897
	1.03	-3,900	-3,713	-3,526	-3,339	-3,152	-2,965	-2,778	-2,591	-2,404
	1.06	-5,455	-5,137	-4,819	-4,500	-4,182	-3,864	-3,546	-3,227	-2,909
	1.09	-7,895	-7,350	-6,805	-6,260	-5,715	-5,169	-4,624	-4,079	-3,534
	1.12	-11,846	-10,918	-9,991	-9,063	-8,135	-7,208	-6,280	-5,353	-4,425

b. "Without"—Kerosene Not Used in Diesel or Heating Oil (Scenario II)

		Change in Average Real Price of Crude Oil (Base Case = 1.00 = $49.45/Barrel)								
Variation Factor in Demand for Diesel and Heating Oil (Base Case = 1.00)	**-1,600**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**	**1.05**	**1.10**	**1.15**	**1.20**
	0.88	-1,129	-919	-709	-499	-289	-79	131	341	551
	0.91	-1,161	-1,030	-899	-768	-637	-506	-375	-244	-113
	0.94	-1,336	-1,230	-1,125	-1,020	-915	-810	-705	-600	-495
	0.97	-1,667	-1,553	-1,439	-1,325	-1,211	-1,097	-983	-869	-755
	1.00	-2,217	-2,063	-1,909	-1,754	**-1,600**	-1,446	-1,292	-1,138	-984
	1.03	-3,108	-2,875	-2,641	-2,408	-2,174	-1,941	-1,707	-1,474	-1,240
	1.06	-4,556	-4,185	-3,814	-3,443	-3,072	-2,701	-2,330	-1,959	-1,587
	1.09	-6,925	-6,323	-5,721	-5,118	-4,516	-3,914	-3,312	-2,710	-2,107
	1.12	-10,826	-9,839	-8,851	-7,864	-6,876	-5,889	-4,901	-3,914	-2,926

Table 7. Two-Way Sensitivity Test between Real Price of Crude Oil and Demand for Diesel and Heating Oil – Impacts on the Net Economic Benefits ($ M) (continued)[26]

c. "Without"—Kerosene Used in Heating Oil Only (Scenario III)

		Change in Average Real Price of Crude Oil (Base Case = 1.00 = $49.45/Barrel)								
Variation Factor in Demand for Diesel and Heating Oil (Base Case = 1.00)	**-2,195**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**	**1.05**	**1.10**	**1.15**	**1.20**
	0.88	-3,219	-3,006	-2,794	-2,581	-2,368	-2,155	-1,942	-1,729	-1,516
	0.91	-572	-441	-310	-179	-48	83	214	345	475
	0.94	-1,189	-1,113	-1,036	-960	-884	-808	-732	-656	-580
	0.97	-1,802	-1,741	-1,680	-1,620	-1,559	-1,498	-1,437	-1,377	-1,316
	1.00	-2,497	-2,422	-2,346	-2,271	**-2,195**	-2,120	-2,044	-1,968	-1,893
	1.03	-3,447	-3,326	-3,204	-3,082	-2,960	-2,839	-2,717	-2,595	-2,474
	1.06	-4,886	-4,676	-4,466	-4,256	-4,046	-3,835	-3,625	-3,415	-3,205
	1.09	-7,176	-6,812	-6,448	-6,085	-5,721	-5,357	-4,993	-4,630	-4,266
	1.12	-10,905	-10,282	-9,659	-9,035	-8,412	-7,789	-7,166	-6,542	-5,919

[26] For crude oil, "1" indicates that the crude oil price equals its long-run average price of $49.45/barrel. For biodiesel, "1" indicates that prices of soy, canola, and tallow are at their initial (base case) level of $1.01/liter, $1.01/liter, and $0.91/liter, respectively. Deviations above 1 indicate an increase above initial prices; deviations below 1 indicate a decrease.

Table 8. Two-Way Sensitivity Tests Between Real Crude Oil Price and Real Domestic Biodiesel Production Cost – Impacts on Net Economic Benefits ($ M)[27]

a. "With"—Kerosene Used in Both Diesel and Heating Oil (Central/Scenario I)

Change in Domestic Biodiesel Production Cost (Base Case = 1.00)	*Change in Average Real Price of Crude Oil (Base Case = 1.00 = $49.45/Barrel)*								
-2,368	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**	**1.05**	**1.10**	**1.15**	**1.20**
0.80	**-1,898**	-1,780	-1,663	-1,545	-1,427	-1,310	-1,192	-1,074	-957
0.85	-2,133	**-2,016**	-1,898	-1,780	-1,663	-1,545	-1,427	-1,310	-1,192
0.90	-2,368	-2,251	**-2,133**	-2,015	-1,898	-1,780	-1,662	-1,545	-1,427
0.95	-2,604	-2,486	-2,368	**-2,251**	-2,133	-2,015	-1,897	-1,780	-1,662
1.00	-2,839	-2,721	-2,603	-2,486	**-2,368**	-2,250	-2,133	-2,015	-1,897
1.05	-3,074	-2,956	-2,838	-2,721	-2,603	**-2,485**	-2,368	-2,250	-2,132
1.10	-3,309	-3,191	-3,074	-2,956	-2,838	-2,721	**-2,603**	-2,485	-2,368
1.15	-3,544	-3,426	-3,309	-3,191	-3,073	-2,956	-2,838	**-2,720**	-2,603
1.20	-3,779	-3,662	-3,544	-3,426	-3,309	-3,191	-3,073	-2,955	**-2,838**

b. "Without"—Kerosene Not Used in Diesel or Heating Oil (Scenario II)

Change in Domestic Biodiesel Production Cost (Base Case = 1.00)	*Change in Average Real Price of Crude Oil (Base Case = 1 .00= $49.45/Barrel)*								
-1,600	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**	**1.05**	**1.10**	**1.15**	**1.20**
0.80	**-1,278**	-1,124	-970	-816	-662	-507	-353	-199	-45
0.85	-1,513	**-1,359**	-1,205	-1,050	-896	-742	-588	-434	-280
0.90	-1,748	-1,593	**-1,439**	-1,285	-1,131	-977	-823	-668	-514
0.95	-1,982	-1,828	-1,674	**-1,520**	-1,366	-1,211	-1,057	-903	-749
1.00	-2,217	-2,063	-1,909	-1,754	**-1,600**	-1,446	-1,292	-1,138	-984
1.05	-2,452	-2,297	-2,143	-1,989	-1,835	**-1,681**	-1,527	-1,372	-1,218
1.10	-2,686	-2,532	-2,378	-2,224	-2,070	-1,915	**-1,761**	-1,607	-1,453
1.15	-2,921	-2,767	-2,613	-2,458	-2,304	-2,150	-1,996	**-1,842**	-1,687
1.20	-3,156	-3,001	-2,847	-2,693	-2,539	-2,385	-2,230	-2,076	**-1,922**

[27] Numerical results are reported for scenarios I and II. The shares of fuel inputs are more or less the same in scenarios I and II (see Figure 1, page 18). For crude oil, "1" indicates that the crude oil price equals its long-run average price of $49.45/barrel. For biodiesel, "1" indicates that prices of soy, canola, and tallow are at their initial (base case) level of $1.01/liter, $1.01/liter, and $0.91/liter, respectively. Deviations above 1 indicate an increase above initial prices; deviations below 1 indicate a decrease. See footnote 23 on page 20 and footnote 25 on page 21.

Tables 8(a) and 8(b) present the results of two-way sensitivity analysis of net economic benefits under scenarios I and II, between crude oil prices (which determines prices of refined petroleum products) and production costs of biodiesel. In both cases, as either the price of crude oil increases or the cost of biodiesel decreases, the net economic benefits from the substitution of diesel fuel for biodiesel increase, as expected. Under scenario II, however, net economic benefits are positive only if the price of crude oil rises by at least 20% and the cost of producing biodiesel falls by 20%. Under scenario I, positive net economic benefits are realized only once the price of crude oil rises by 30% and the cost of producing biodiesel falls by 30%. This is very unlikely.

The discount rate most appropriate to the evaluation of environmental interventions has been the topic of some discussion in Canada. The Canadian Regulatory Cost Benefit Guide suggests a real rate of 8% (2007 p 35-39). However, it also advises that an intervention's sensitivity to the discount rate be tested by re-estimating results using a rate of 3%.

The analysis of the intervention presented thus far is based on a 3% discount rate. In order to assess the sensitivity of outcomes to changes in the discount rate, the net present value (NPV) of economic benefits under each scenario are re-estimated using an 8% real discount rate, producing the following results.

A higher discount rate results in greater (or less negative) estimated net economic benefits under all scenarios compared to the base case (see Table 4, row E). Under scenario I, the NPV of economic benefits using an 8% discount rate is -\$1.5 billion, compared to -\$2.46 billion using a 3% discount rate. Under scenario II, the NPV is -\$1.0 billion at a discount rate of 8% compared to -\$1.6 billion at a rate of 3%, and under scenario III, it becomes -\$1.4 billion at 8% compared to -\$2.2 billion at 3%. These figures are contrary to the frequent claim that a lower discount rate improves the NPV of an environmental intervention, due to the fact that in this case, the proposed amendment generates negative net benefits.

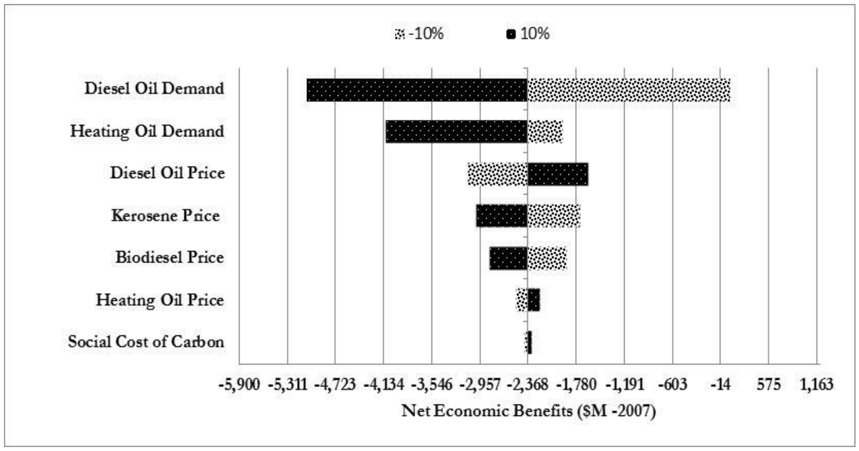
In terms of cost per liter of fuel, an 8% real discount rate results in a lower average additional cost under all scenarios, falling from 0.26¢/liter to 0.16¢/liter under scenario I, from 0.18¢/liter to 0.11¢/liter under scenario II, and from 0.24¢/liter to 0.15¢/liter under scenario III (see Table 4, row F). Sensitivity analysis therefore indicates that both the net present value of economic benefits, and average costs per liter of diesel and heating fuel, are sensitive to the real discount rate, and that both improve at the higher rate of 8%.

Sensitivity analysis determines the direction and magnitude of changes in outcomes associated with the adjustment of key variables. Figures 3 a, b, and c rank the relative magnitude of risk variables' impact on the NPV of economic benefits of the intervention.[28]

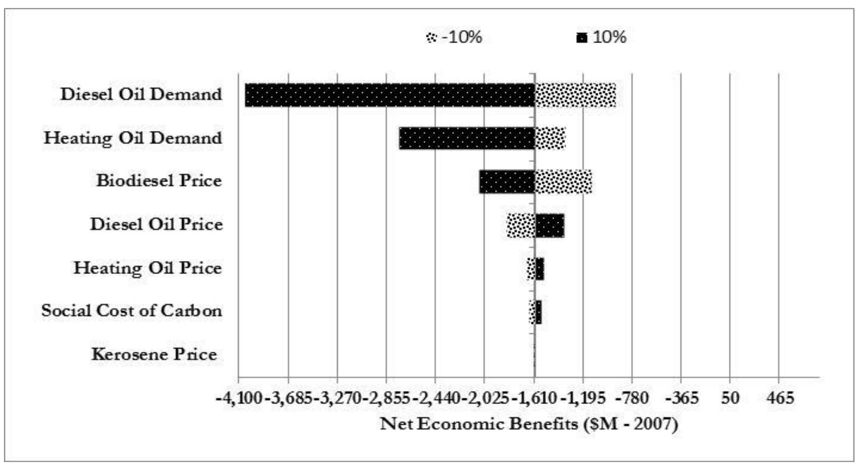
[28] To ensure consistency in the risk assessment, the right and left tails of the tornado diagrams' x-axes cover a similar range (+,-) to the deterministic estimate (e.g. -4700 - 2338, 0 for scenario I).

Figure 3. Tornado Sensitivity Tests on Net Economic Benefits ($M)

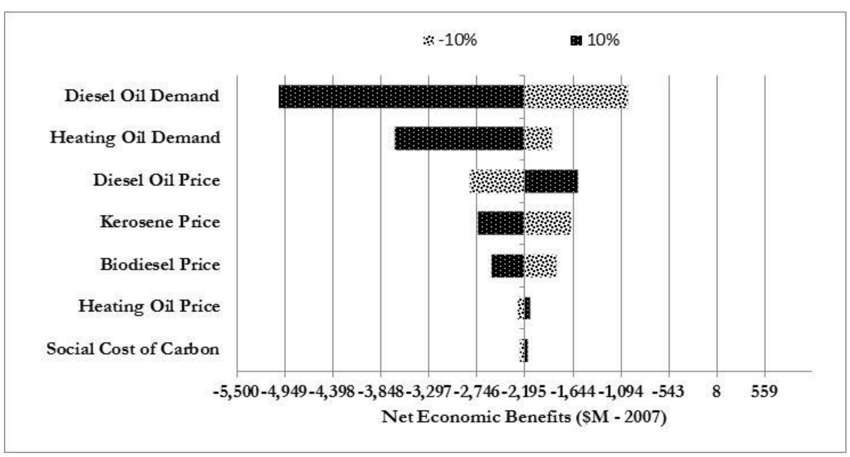
a. "With"—Kerosene Used in Both Diesel and Heating Oil (Central/Scenario I)



b. "Without"—Kerosene Not Used in Diesel or Heating Oil (Scenario II)



c. "Without"—Kerosene Used in Heating Oil Only (Scenario III)



The longer the bar in the tornado diagram, the greater the sensitivity of outcomes to the factor concerned. The end-points of a bar indicate the impact of a factor on the outcome at low (e.g. -10%) and high (e.g. +10%) variability from the base case. Factors are arranged from the top down, according to degree of impact. Although the impact of a factor's variability is presented at +/-10%, it should be noted that prices of refinery products and biodiesel are subject to a higher level of uncertainty and variability than are levels of demand for diesel and heating oil. Sensitivity analysis indicates that net economic benefits are most sensitive to a +/-10% change in projected demand for diesel and for heating oil (particularly in the negative direction), under all three scenarios considered. Since the total impact on outcomes of this factor is significant, it is considered an important cause of variability associated with the intervention.

Under scenarios I and III, the third and fourth most important risk variables are the price of diesel and of kerosene. Under scenario II, however, the price of biodiesel is the third-highest ranking variable in terms of impact on net economic benefits, while the price of diesel is ranked fourth. In all cases, a +/-10% change in the social cost of carbon ($/per ton of CO_2) has relatively little impact.

Monte Carlo Risk Analysis

The proposed Amendment regarding renewable fuels entails risk and uncertainty factors that have important long-term effects on expected costs and benefits associated with the intervention. However, the risk and uncertainty associated with crude oil prices and future demand for energy are always present.

A Monte Carlo simulation serves as a means of quantitative risk analysis, expressing the value of inputs subject to risk as probability distributions.[29] The values of these risk variables are selected according to sensitivity analysis, and defined according to the ranges of their possible values and the specified probability distributions (see Table 9).[30] The output of this analysis provides estimates of expected values and probability distributions of net economic benefits, and the cost per liter of diesel and of heating oil demanded.

[29] For a step-by-step guide to conducting a Monte Carlo analysis, see Appendix A, page 35.

[30] In this study the process is repeated 100,000 times to produce project results for probability distributions and statistics. While there is always a degree of error associated with such simulations, the larger the number of random samples taken, the better the shape of the probability distribution and the more accurate the result. The total duration for this simulation was about 14 minutes at its fastest.

Table 9. Probability Distributions of Risky/Uncertain Variables

Risk Variables	Probability Distribution[31]
Real Price of Crude Oil ($/barrel)	Custom distribution, constructed using annual real price of crude oil price data from 1974 to 2015. The ranges of real crude oil prices and their probabilities are applied on an annual basis.
Real Price of Domestic Biodiesel Production from Soy, Canola and Tallow ($/liter)	Normal distribution, with a standard deviation of 10%, applied on an annual basis for different inputs used in the production of biodiesel. There is a correlation between "price of diesel oil" and "price of biodiesel".[32] Diesel prices are indexed to crude oil prices, therefore there is also a correlation between crude oil prices and biodiesel prices.
Social Cost of Carbon ($/T)	While rightly viewed as an uncertain variable, a customized distribution of the values of this parameter was obtained from a meta-analysis of a series of environmental-impact models.[33] The distribution of values (frequency distribution) is "skewed" to the right and is not symmetrical (see Appendix B).
Variation in Diesel/Heating Oil Demand (%)	A symmetric triangular distribution is used, in which values have upper (10% above central value) and lower (10% below central value) limits.

[31] See Appendix B on page 36 and 37.
[32] See, Pokrivcak and Rajcaniova, 2011, p.397, 398; Asche et al. 2003, p.294; Tareen et al., 2000, p.378.
[33] See, Greenstone et al. 2013, p.19, Johnson and Hope, 2012, US EPA, 2010.

Simulation Results and Their Interpretation[34]

For the purposes of comparison, it useful to present the results of simulations plotted as both **cumulative** and **non-cumulative probability distributions**. The cumulative probability distribution of the Amendment's net impacts is useful for making decisions involving alternative scenarios or interventions. The non-cumulative distribution is better for indicating the mode of the distribution and for understanding concepts related to expected values. Because different scenarios are considered here, results are compared using overlay charts that show the risk curves of different scenarios.[35] Probability distributions for the net economic costs of alternative scenarios (see Figure 4) and for average costs per liter of diesel/heating oil consumed (see Figure 5) are also presented.

Summary statistics from simulations on the net economic costs of alternative scenarios, and on average costs per liter diesel/heating oil consumed, are presented in Tables 10 and 11, respectively. Cost estimates from risk simulations and expected changes in emission levels are presented in Table 12.

Interpreting Simulations of Net Economic Benefits ($M)

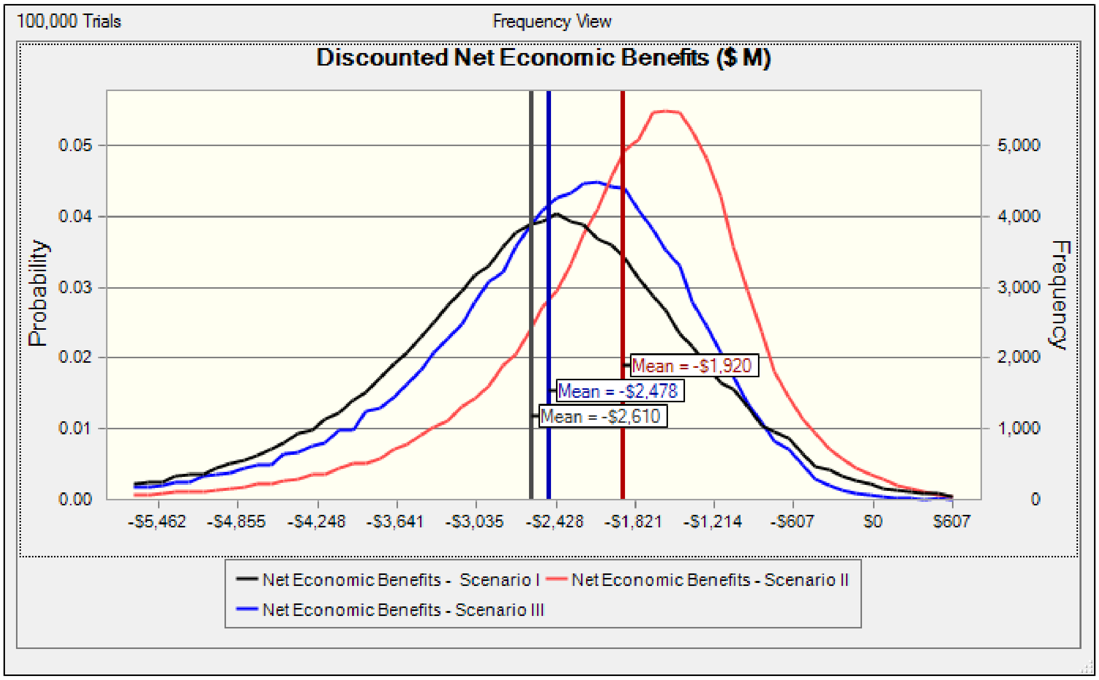
Using deterministic (base case) results, the net economic benefits of the intervention under scenarios I, II, and III are estimated at minus $2.4 billion, minus $1.6 billion, and minus $2.2 billion, respectively. The incorporation of risk and uncertain variables into the Monte Carlo simulations results in still lower net economic benefits under each scenario– minus $2.6 billion, minus $1.9 billion, and minus $2.5 billion, respectively. The probabilistic risk assessment therefore indicates that incorporating risk and uncertainty will have a negative impact on expected outcomes under all three scenarios, with the greatest absolute impact under scenario II (approximately 20% worse), followed by scenario III (approximately 13% worse), and scenario I (approximately 10% worse).

Based on the probability distributions presented in Figure 4a, this Amendment is unlikely to yield positive net economic benefits under any of the three scenarios. The cumulative distributions presented in Figure 4b indicate that expected net economic benefits under scenario II are greater than those under scenarios I and scenario III.[36] However, even under scenario II the probability that the intervention will yield a positive NPV is almost zero.

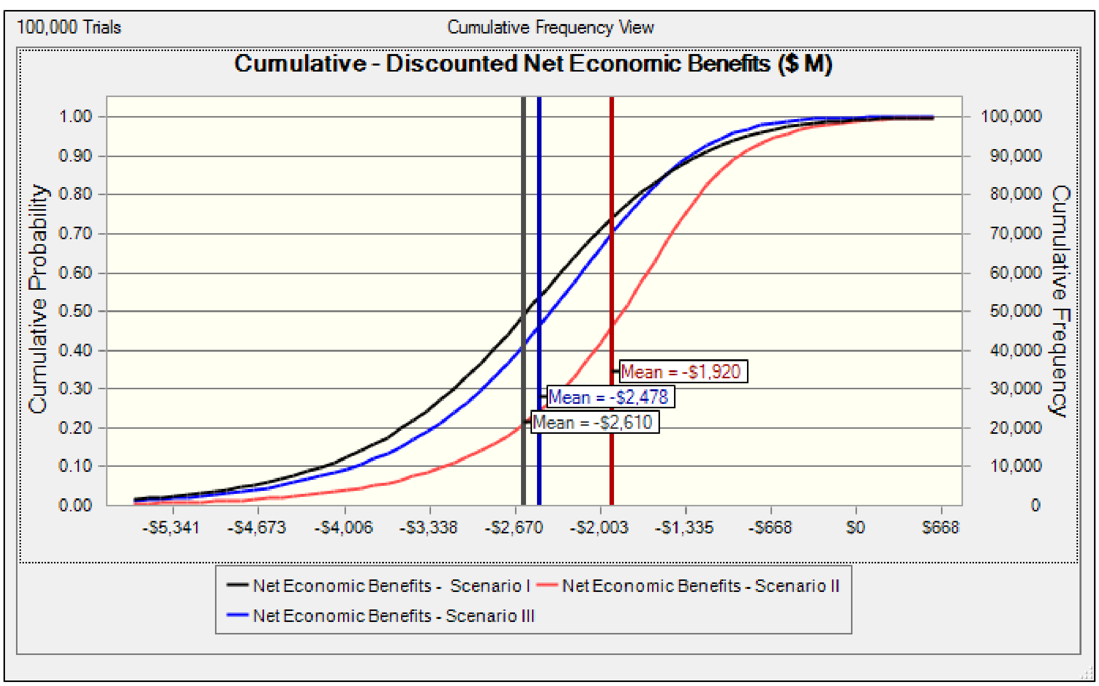
[34] After simulations have been completed, the spreadsheet model generates a risk report ("Risk Report").
[35] Individual simulation results of forecasts (net economic benefit, cost per liter of oil consumed) are presented before the "assumptions" of the "Risk Report", while overlay charts are presented as "end of assumptions" on the "Risk Report" sheet.
[36] If, for example, the cumulative probability distributions of net economic benefits for mutually exclusive scenarios intersect, then risk-taking (risk-averse) selection would be the scenario allowing for a greater (lesser) economic benefit with a greater probability of a negative return. This comparison requires overlay cumulative probability distribution graphs.

Figure 4. Probability Distributions of Net Economic Benefits ($M)

a. Probability Distributions



b. Cumulative Probability Distributions



Source: Authors' simulations.

Table 10. Descriptive Statistics from Simulations on Net Economic Benefits ($M)

Statistics/Scenario	Scenario I	Scenario II	Scenario III
Trials	100,000	100,000	100,000
Base Case	-2,368	-1,600	-2,195
Mean	-2,610	-1,920	-2,478
Median	-2,524	-1,780	-2,336
Standard Deviation	1,190	990	1,082

Source: Authors' simulations.

Interpretation of Average Cost (cents/liter) of Expected Emissions Reductions (MTCO2e) from Simulations

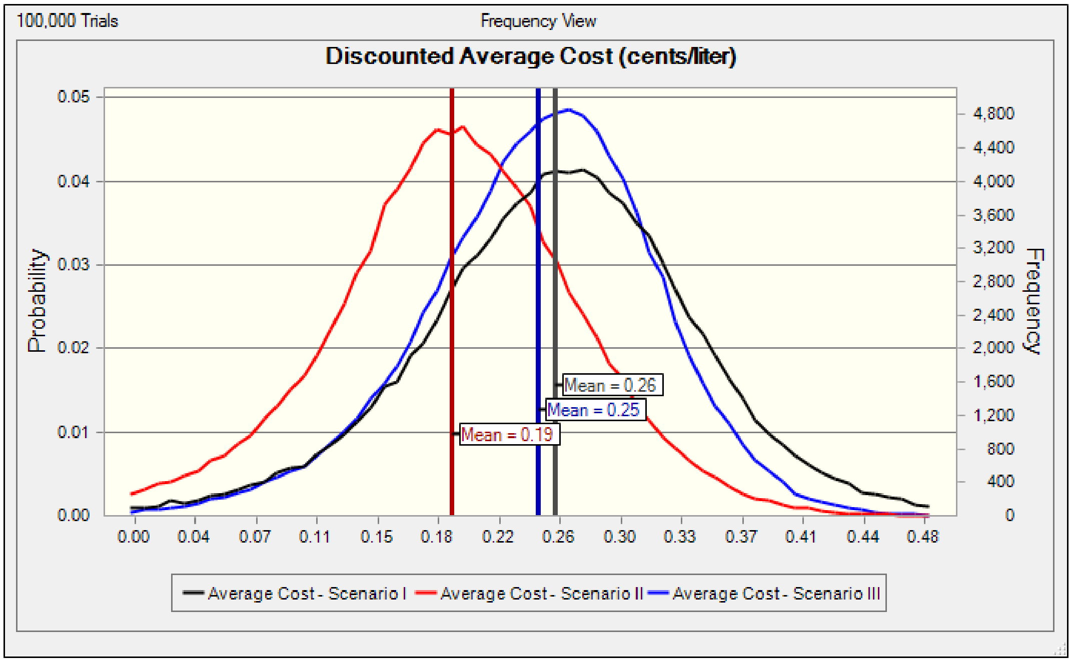
Based on deterministic results (see Table 4, row G), the estimated cost of the intervention per liter of diesel/heating oil consumed under scenarios I, II, and III is 0.26¢, 0.18¢, and 0.24¢, respectively. Incorporating risk and uncertain via the Monte-Carlo simulations, the expected per-liter costs of the intervention rise to 0.19¢ and 0.25 ¢ under scenarios II and III, while remaining almost the same for scenario I at 0.26¢ (Figure). A probabilistic risk assessment therefore indicates that taking account risk and uncertainty increases average per-liter costs of the intervention under scenarios II (by 5.6%) and III (by 4.2%), but has effectively no impact under scenario I.

A comparison of the impact on the average cost per liter of diesel and heating oil consumed (Table 11) with expected reductions in emissions (Table 12) suggests that the expected rise in costs per liter consumed will lead to greater emissions reductions under scenario II as compared to scenarios I and III.

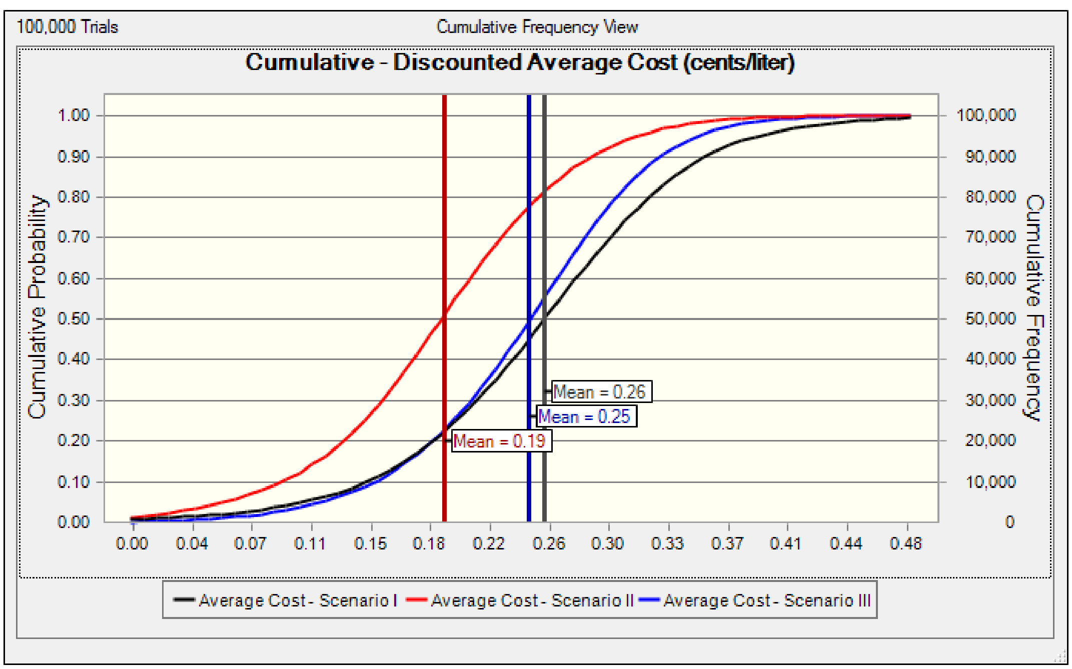
In summary, simulations indicate that the 2% renewable-fuel content required by the Amendment will be achieved at least cost under scenario II. As illustrated by Figure 5b, there is a 79% probability of achieving the 2% target at a lower cost per liter under scenario II than under the second-cheapest policy option, scenario III. That is, scenario II is characterized by lower costs per liter at a smaller risk of not achieving higher levels of emission reductions—this being the scenario in which kerosene is not used in either diesel or heating oil.

Figure 5. Probability Distributions of Average Costs (cents/liter of diesel and heating oil)

a. Probability Distributions



b. Cumulative Probability Distributions



Source: Authors' simulations.

Table 11. Descriptive Statistics from Simulations on Average Costs (cents/liter of diesel and heating oil)

Statistics/Scenario	Scenario I	Scenario II	Scenario III
Trials	100,000	100,000	100,000
Base Case	0.26	0.18	0.24
Mean	0.26	0.19	0.25
Median	0.26	0.20	0.25
Standard Deviation	0.09	0.08	0.07

Source: Authors' simulations

Table 12. Descriptive Statistics from Simulations on Total GHS Reductions (MT CO2e)[37]

Statistics/Scenario	Scenario I	Scenario II	Scenario III
Trials	100,000	100,000	100,000
Base Case	22.4	23.6	20.1
Mean	27.9	28.9	25.0
Median	23.7	24.9	20.7
Standard Deviation	13.9	14.3	13.6

Source: Authors' simulations.

Overview of how risk and uncertainty are evaluated and presented

The evaluation and presentation of risk and uncertainty entail the following steps. First, three scenarios (characterized by use or non-use of kerosene) are set out, under which the renewable-fuel content levels required under the Amendment would be met. The impact of the Amendment on these alternative scenarios is then evaluated using deterministic input values, and presented by scenario. The results indicate that the net present values of economic benefits of the intervention are negative under all three scenarios, with values ranging from minus $1.6 billion to minus $2.4 billion.

Second, the key variables that affect outcome results and are subject to risk or uncertainty are identified and described. The impacts of these key variables are then quantified, using the commonly applied technique of sensitivity analysis, and the results presented in the

[37] Total emission changes from risk simulations are due to "variations in demand for diesel and heating oil" @ a target of 1.96%. Emission reductions come from displaced diesel and heating oil, net of emissions generated from fuels used to meet the 2% target for renewable content. Emissions savings are greater than in the base case under all scenarios, indicating that 10% variations in diesel and heating oil (with variations randomly selected), will generate lower emissions than the deterministic estimate.

form of tornado diagrams. The key variables found to generate variability in results are demand for diesel and heating oil, and the prices of diesel oil, kerosene, and biodiesel.

Third, the key variables are classified as those subject to risk, and those that are uncertain. Fuel prices are considered risk variables, while growth in demand for diesel and fuel oil, along with the social cost of carbon, are considered to be uncertain. Ranges and probability distributions are then developed for each of these variables.

Finally, probabilistic risk simulation is conducted to assess the impact of variability on the outcome of a policy aimed at achieving a 2% target for renewable-fuel content, as proposed by the government of Canada.

The results of the risk simulation indicate that the higher variable cost impact of the crude oil price outweighs the benefits of an increase in crude oil prices, under all scenarios. When all risk variables are simultaneously incorporated, the net negative impacts are greatest under scenario II. Nonetheless, we expect that the net economic cost of achieving a 2% renewable-fuel content will be 20-25% lower under scenario II than scenarios I and III. Indeed, when costs are distributed over the volume of diesel/heating oil consumed, the per-liter net economic cost to consumers will be considerably less under scenario II. At the same time, expected reductions in emissions are also greater under scenario II than scenarios I and III. Furthermore, scenario II entails lower risks, as well as lower costs. To conclude, consumers and the environment alike would be better off under scenario II, in which kerosene is not used.

The risk-analysis component of a CBA of the Renewable Fuels Regulation Amendment greatly increases understanding of how the interaction of key variables impacts expected outcomes. It does not, however, alter the basic conclusion established by the base case, which is that the amendment is expected to generate substantially fewer economic benefits than the economic costs it is expected to impose.

4. Conclusions

The systematic incorporation of the impacts of risk and uncertainty into the cost-benefit analysis of regulations has become standard practice across most industrialized countries and multilateral agencies. The step-by-step guidelines presented here are based on a review of those national and multilateral agencies' CBA frameworks, to produce a comprehensive approach to the assessment of risk and uncertainty, including scenario, sensitivity, and Monte Carlo risk analysis, developed and presented for an ex-ante analysis of regulatory proposals.

The initial steps in such an analysis are critical, as it is at this point that the important variables which generate variation in the outcomes of the intervention are identified. Sensitivity analysis and the defining of relevant scenarios further enhance understanding of the causes of variability of outcomes. In many cases, where there is irrefutable evidence that the outcome of the analysis will always be either positive or negative, it will not be necessary to go any further.

However, decision-makers will be better able to appreciate the likely range of values and the probabilities associated with different levels of outcome if the CBA incorporates variability of risk and uncertain variables, along with their correlations. Following such a full risk analysis, probabilistic estimates can be presented using non-cumulative and cumulative probability charts, alongside their descriptive statistics.

This report demonstrates an application of the approach outlined, to the proposed Amendment to blend renewable fuels into diesel and heating oil. Although any given regulatory change will have unique elements, the step-by-step approach presented here, including the spreadsheet model, can serve as a guide to assessing the impact of variability on the outcomes of any CBA. Each new application will enhance the quality and ease of analysis, improving the information available for informed decision-making.

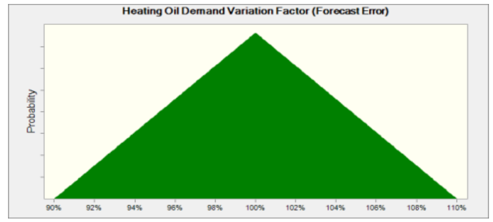
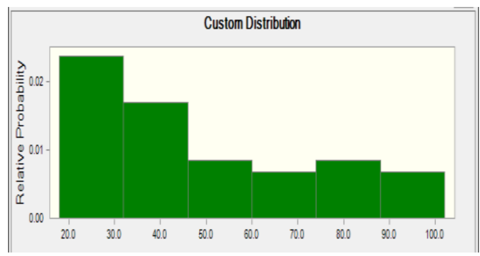
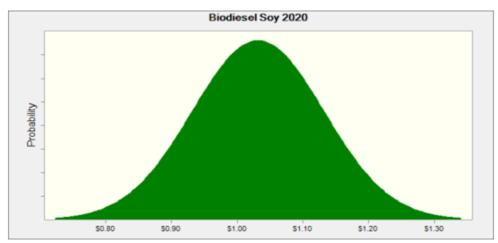
Appendices

Appendix A: Building a Monte Carlo Simulation Spreadsheet Model

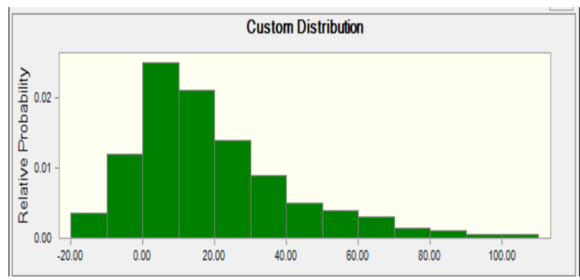
Steps	Procedures
Step 1: Preliminary Analysis	1.1 Define risky and uncertain inputs. 1.2 Classify inputs as "market risk/uncertainty" or "non-market risk/uncertainty."
Step 2: Sensitivity Test	2.1 Check/debug if calculations and/or relationships between inputs are linked correctly. 2.2 Detect which variables have a larger impact on outcomes and evaluate degree of risk/uncertainty in these variables.
Step 3: Probability Studies	3.1 Assign probability distributions for risky and uncertain input variables. 3.2 Check correlations between risky and uncertain input variables. 3.3 Design scenarios for non-market risks (e.g. regulatory risks, such as federal renewable fuel target, kerosene use, etc.).
Step 4: Risk Simulation and Run Preferences	4.1Define "risk assumptions"[38] - apply probability distribution on selected key input values and correlations, if any. 4.2 Select output parameters/"define forecast"[39] from simulation results (e.g. net economic benefit, cost per liter of fuel demanded). 4.3 Select run preferences, such as "number of trials", "speed", etc. and run simulations.
Step 5: Presenting/ Interpreting Simulation Results	5.1 Organize probability and cumulative probability charts. 5.2 Extract "probability/cumulative probability distributions" and "descriptive statistics." 5.3 Interpret simulation results using normal and cumulative distributions, and supplement interpretations with statistical measures. 5.4 Discuss options for reducing/managing risks.

[38] In our spreadsheet model, **input** values are presented in "**Inputs & Sensitivity Test**," in which all calculations are based upon these deterministic values. When defining probability distribution, any calculation in risk parameter cell must be removed. For example in the case of crude oil, probability distributions are defined in different cell range 54 and linked to cell range 52 (see Risk Data sheet and Inputs & Sensitivity Tests). The prices of kerosene, diesel/heating oil are based on changes in cell range 52, preserving causality between crude oil and refinery products during simulations.
[39] In our spreadsheet model, forecast values are presented in "**Summary Tables – Aggregate Level,"** in which all **output** calculations are made and presented.

Appendix B: Risk Variables, Their Ranges and Probability Distributions[40]

Variable	Base Value	Distribution Type	Description
Variation in Diesel Oil Demand (Cell C45) **Variation in Heating Oil Demand (Cell C46)**	100% 100%	**Triangular Distribution** 	**Minimum** 90% **Likeliest** 100% **Maximum** 110%
Real Price of Crude Oil ($/Barrel) (Cell Range C54-AA54)	49.45	**Custom Distribution** 	<u>**From**</u> <u>**To**</u> <u>**Likelihood**</u> 18 32 33.3% 32 46 23.8% 46 60 11.9% 60 74 9.5% 74 88 11.9% 88 102 9.5%
Real Price of Domestic Biodiesel Production ($/liter) **1. Soy: Cell Range C202:AA202** **2. Canola: Cell range C203:AA203** **3. Tallow: Cell range**	 1.01 1.01 0.91	**Normal Distribution** 	**Mean** 100% **Standard Deviation** 10% **Correlation Coefficient = +0.90** Between real crude oil price and real price of Canadian biodiesel.

[40] See "Risk Data" in spreadsheet.

Variable	Base Value	Distribution Type	Description
C204:AA204			
Social Cost of Carbon ($/tonne) **Cell C222**	23.9	**Custom Distribution**  	**From To Likelihood** -20 -10 4% -10 0 12% 0 10 25% 10 20 21% 20 30 14% 30 40 9% 40 50 5% 50 60 4% 60 70 3% 70 80 2% 80 90 1% 90 100 1% 100 110 1%

References

Asche, F., Gjølberg, O. and Volker, T. 2003. Price relationships in the petroleum market: an analysis of crude oil and refined product prices. Energy Economics, 25, 289-301.

Asian Development Bank. 2002. Handbook for Integrating Risk Analysis in the Economic Analysis of Projects, Manila, Philippines http://www.adb.org/sites/default/files/institutional-document/32758/files/integrating-risk-analysis.pdf (last accessed on 2016-04-15)

Boardman, E.A., Greenberg, D.H., Vining, A.R., and Weimer, D.L. 2006. Dealing with Uncertainty' in Cost-Benefit Analysis – Concepts and Practice, 3rd Ed., Pearson Prentice Hall, New Jersey, pp. 165-199.

Bock, K., and Truck, S. 2011.Assessing Uncertainty and Risk in Public Sector Investment Projects, Technology and Investment, 2: 105-123.

Borenstein, S., Cameron, C., and Gilbert, R. 1997. Do Gasoline Prices Respond Asymmetrically to Crude Oil Prices? Quarterly Journal of Economics, 112, 305-39.

Canada, Canadian Cost-Benefit Analysis Guide: Regulatory Proposals. 2007. Treasury Board of Canada Secretariat, Canada, 2007, p.4-7; and p. 22-24. http://www.tbs-sct.gc.ca/hgw-cgf/finances/rgs-erdg/wwad-cqnf/col/analys/analys-eng.pdf (last accessed on 2016-04-15)

Canada, Canada Gazette, July 20, 2011, ARCHIVED — Regulations Amending the Renewable Fuels Regulations, 145(15). http://canadagazette.gc.ca/rp-pr/p2/2011/2011-07-20/html/sor-dors143-eng.html (last accessed on 2016-04-15)

Canada, Canadian Regulatory Cost-Benefit Analysis Guide. 2007. Treasury Board of Canada, Secretariat in collaboration with Queen's University and the Cost-Benefit Advisory Committee http://www.queensjdiexec.org/publications/qed_dp_168.pdf (last accessed on 2016-04-15)

Canada, Treasury Board of Canada. 2007. Cost-Benefit Analysis Case Study on Regulations to Lower the Level of Sulphur in Gasoline, in collaboration with Queen's University and the Cost-Benefit Advisory Committee, Authors: Jenkins, G.P, Kuo, C.Y. and Ozbafli, A.

Canada, Natural Resources Canada. 2011. Canadian Crude Oil, Natural Gas and Petroleum Products: Review of 2009 & Outlook to 2030, Petroleum Research Brand, Energy Sector http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/eneene/sources/crubru/revrev/pdf/revrev-09-eng.pdf (last accessed on 2016-04-15)

Canada, Natural Resources Canada, 2014-2015, Energy Markets Fact Book 2014–2015 http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/2014/14-0173EnergyMarketFacts_e.pdf (last accessed on 2016-04-15)

Canada, Environment and Climate Change Canada. April 2016. Canada's Emissions Trends, 1990-2014, https://www.ec.gc.ca/indicateurs-indicators/F60DB708-6243-4A71-896B-6C7FB5CC7D01/GHGEmissions_EN.pdf (last accessed on 2016-04-25)

Clarke, R and Low, A. 1993, Risk Analysis in Project Planning: A Simple Spreadsheet Application Using Monte-Carlo Techniques, Project Appraisal, 8, 3, pp. 141-146

Clarke, H. 2014 "Evaluating Infrastructure Projects Under Risk and Uncertainty: A Checklist of Issuers", Australian Economic Review, 47, 1, 147-156.

Australia, Handbook of Cost-Benefit Analysis. 2006 (latest version). Department of Finance and Administration, Chapter 6: Allowing Risk and Uncertainty, p. 69-79 & Appendix IV: Full Risk Analysis, p.141-144.
http://www.finance.gov.au/sites/default/files/Handbook_of_CB_analysis.pdf (last accessed on 2016-04-15)

Australia, Economic Evaluation for Business Cases. 2013. Technical Guidelines, the Secretary Department of Treasury and Finance, Section 8: Assessing Risk and Uncertainty, p.33-36

Australia, Project Assessment Framework, Cost-Benefit Analysis. 2015. The State of Queensland (Queensland Treasury), Appendix B1 – Risk Assessment, p.25, Appendix B4 – Sensitivity analysis, p.27-28
https://www.treasury.qld.gov.au/publications-resources/project-assessment-framework/paf-cost-benefit-analysis.pdf (last accessed on 2016-04-15)

Coyle, W. 2013. The Future of Biodiesel - A Global Perspective. USDA.gov: http://www.ers.usda.gov/amber-waves/2007-november/the-future-of-biofuels-a-global-perspective.aspx#.Vw09x_krLIU (last accessed on 2016-04-15)

European Union, Guide to Cost-Benefit Analysis of Investment Projects Economic appraisal tool for Cohesion Policy 2014-2020. 2014. European Commission. Directorate-General for Regional and Urban policy
http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf (last accessed on 2016-04-15)

Fao, R., Howard, M. 2006. Use of Monte Carlo Simulation for the Public Sector: An Evidence Based Approach to Scenario Planning, International Journal of Market Research, 48, 27-48

Flyvberg, B. 2009. Survival of the Unfittest: Why the Worst Infrastructure Gets Built, Oxford Economic Review, 25, pp. 344-367

France, Guide de l'analyse coûts-avantages des projets d'investissement, 2003. 2.7.4: Analyse de probabilité des risques, p. 41-45, Annexe D: Analyse de sensibilité et des risques, p.123-125
http://www2.toulouse.inra.fr/lerna/treich/ACB03.pdf(last accessed on 2016-04-15)

France, Gollier, C., Baumstark, L., Fery, P. Dominique A. and Raynard, C. 2011. Le calcul du risque dans les investissements publics
http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/114000605.pdf
(Last accessed on 2016-04-15)

Greenstone, M., Kopits, E. and Wolverton, A. 2011. Estimating the social cost of carbon for use in U.S. federal rulemakings: A summary and interpretation. NBER Working Paper 16913, National Bureau of Economic Research, Cambridge, MA.
http://web.mit.edu/ceepr/www/publications/workingpapers/2011-006.pdf (last accessed on 2016-04-15)

Hillson, D. and Murray-Webster, R. 2004. Understanding and managing risk attitude. Available at:
http://www.kent.ac.uk/scarr/events/finalpapers/Hillson%20%2B%20MurrayWebster.pdf

Jenkins, G.P., 1997, Project Analysis and the World Bank, American Economic Review, 87, 2, pp. 38-42

Jenkins, G.P., Kuo, C-Y., and Harberger, A.C. 2011. Cost-Benefit Analysis for Investment Decisions: Chapter 6: Dealing with Uncertainty and Risk in Investment Appraisal, available under Development Discussion Paper: 2011-6, John Deutsch International, Queen's University, Canada
http://www.queensjdiexec.org/publications/qed_dp_199.pdf (last accessed on 2016-04-15)

Johnson, L.T. and Hope, C. 2012. The social cost of carbon in U.S. regulatory impact analyses: an introduction and critique. J Environ Stud Sci.

Kwak, Y.H., and Ingall, L. 2007. Exploring Monte Carlo Simulation Applications for Project Management, Risk Management, 44-57

Kriger, D., Shie, S., and Naylor, S. 2006. Estimating Toll Road Demand and Revenue: A Synthesis of Highway Practice, Transportation Research Board, NCHRP, Washington DC, US

Lemp, J.D., Kockelman, K.M. 2009. Understanding and Accommodating Risk and Uncertainty in Toll Road Projects: A Review of Literature, Transport Research Record, 2132, 106-112

Li, R. 2010. The Relationships among Petroleum Prices. International Conference on Applied Economics – ICOAE 2010, 459-463

Mietzner, D., and Reger, G. 2005. Advantages and disadvantages of scenario approaches for strategic foresight, Int. J. Technology Intelligence and Planning, 1, 220-239
New Zealand, The Treasury, Guide to Social Cost Benefit Analysis. 2015. Issues in Cost Benefit Analysis, p.50-51 & Appendix 1: Monte Carlo Simulation, p.60-61 http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/guide/cba-guide-jul15.pdf (last accessed on 2016-04-15)

Pokrivcak, J., and Rajcaniova, M. 2011. Crude oil price variability and its impact on ethanol prices. Agric Econ - Czech, 8, 394-403.

Sanderson, J. 2012. Risk, Uncertainty and Governance in Megaprojects: A Critical Discussion of Alternative Explanations, International Journal of Project Management, 30, 432-443

Savvides, S. 1994. Risk Analysis in Investment Appraisal, Project Appraisal, 9, 1-30

Tareen, I.Y., Wetzstein, M.E., Duffield, J.A. 2000. Biodiesel as a substitute for petroleum diesel in a stochastic environment. Journal of Agricultural and Applied Economics, 32, 373-381.

United Kingdom, the Green Book, Appraisal and Evaluation in Central Government. 2015. HM Treasury of the United Kingdom, Treasury Guidance, Chapter 5: Appraising the Options, p. 17-34 & Annex 4 Risk and uncertainty, p.79-88 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf (last accessed on 2016-04-15).

United States of America, Environmental Protection Agency, US EPA. May 2014. Guidelines for Preparing Economic Analyses
https://www.epa.gov/sites/production/files/2014-11/documents/montecar.pdf (last accessed on 2016-04-15).
http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-50.pdf/$file/EE-0568-50.pdf

United States of America, Environmental Protection Agency, US EPA, 1997 Guiding principles for Monte Carlo analysis. Risk Assessment Forum, Washington, DC. http://www.epa.gov/osa/basic-information-about-risk-assessment-guidelines-development

United States of America, White House, January 11 1996. Economic Analysis of Federal Regulations, Executive Order 12866
https://www.whitehouse.gov/omb/inforeg_riaguide (last accessed on 2016-04-15).

United States of America, Environmental Protection Agency, US EPA. 2010. Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866 Interagency Working Group on Social Cost of Carbon https://www3.epa.gov/otaq/climate/regulations/scc-tsd.pdf (last accessed on 2016-04-15)

Van Gronendal, W.J.H., and Kleijnen, J.P.C. 2002. Deterministic versus Stochastic Sensitivity Analysis in Investment Decisions: An Environmental Case Study, European Journal of Operational Research, 141, 8-20

Zwikael, O., and Ahn, M. 2011. The effectiveness of risk management: An analysis of project risk management planning across industries and countries. Risk Analysis, 31, 25-37