Appendix 6.2
Social Cost of Carbon

Final Report

A Social Cost of Carbon for Informing Energy-Climate Policy in the Yukon

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Summary

The social cost of carbon (SCC) is a monetary value that indicates the net harm of human CO2 emissions from burning coal, oil and natural gas (fossil fuels). The SCC is usually measured in dollars per tonne of CO2 ($/tCO2). The Yukon Energy Corporation seeks a value for the SCC that it might use to guide energy investments and other planning and policy decisions.

While there are many reasons why estimates of the SCC can diverge significantly, two stand out. The first is that the SCC must include harm to what are sometimes called the earth's unmanaged systems, for which we cannot readily attribute monetary values. Reduced output from agriculture, forestry and fisheries will result in monetary losses that can be tabulated. In contrast, the extinction of a non-commercial species, such as the polar bear, or the destruction of a major ecosystem, like the Amazon rainforest, is not directly linked to lost market products. The efforts of researchers to address this uncertainty has led to a steady rise in the SCC value used by, for example, the US Environmental Protection Agency, and to its conclusion that its SCC estimates are likely still biased downward. The second major reason for diversity is that some SCC estimates place little value on low probability catastrophic outcomes, such as runaway methane release in the Arctic, collapse of the West Antarctic Ice Sheet, and reversal of the Gulf Stream. More recent SCC estimates attempt to somehow incorporate these potential costs, but there is great uncertainty about what values to use.

The US EPA uses a wide range of values for the SCC when assessing its proposed regulations, such as vehicle or coal plant emissions standards. Because it does not apply a single SCC value, some regulations may be pursued even if not justified according to the lowest values.

In Canada, governments have not used the SCC in such a transparent manner. Instead, four provincial governments are enacting explicit carbon pricing (via a carbon tax, or the price of tradable permits in a cap-and-trade system) covering over 30 million Canadians. These carbon prices are $15 to $30 /tCO2, with provisions in three cases to rise at 5% plus inflation.

At the same time, Canadian provincial governments have enacted other policies that direct crown corporations and in some cases private corporations to shift toward lower emission technologies, especially in electricity generation. It is possible to compute the 'implicit' carbon price for these policies, which is the level of carbon tax that would have been needed to get the same outcome. These implicit carbon prices are in the range of $100 /tCO2 or higher.

Background

The social cost of carbon (SCC) is a monetary value that indicates the net harm of human CO2 emissions from burning coal, oil and natural gas (fossil fuels). The SCC is usually measured in dollars per tonne of CO2 ($/tCO2), but sometimes dollars per tonne of carbon ($/tC).

The harms human CO2 emissions cause to people, the economy and the environment are called 'externality costs' if they are not included ('internalized') in the prices of goods and services that cause these emissions. These harms result from rising CO2 concentrations in the atmosphere and oceans. In the atmosphere, the CO2 raises global temperatures resulting in desertification in some regions, more extreme weather events (floods, droughts, heat waves, hurricanes), rising sea levels (from accelerated melting of glaciers and ice sheets), accelerated species extinction (from rapid ecosystem change), and reduced net global economic output (though some regions may initially experience net benefits from modest levels of warming). In the oceans, the rising CO2 concentration causes acidification, which reduces biological productivity and economic output.

Yukon Energy Corporation seeks to adopt one value, or a range of values, for the SCC that it might use to guide energy investments and other planning and policy decisions. This briefing document explains the SCC concept and how experts estimate its value. It then provide various estimated SCC values, and comments on their significance and potential applicability to Yukon Energy, notably by providing examples of how other governments, corporations and agencies use the SCC and related concepts.

The Challenge of Estimating the Social Cost of Carbon

For over two decades, William Nordhaus of Yale University has played a leading role in the estimation of the SCC.[1] Because the initial stages of global warming may increase agricultural productivity in colder regions of North America and Eurasia, he notes that the SCC should be computed as a 'net' value, in which the benefits of global warming are subtracted from the costs.

When estimating these costs, Nordhaus divides the earth into managed and unmanaged systems.[2] Managed systems are resources that humans use to produce market products. Examples are ocean fish stocks, agricultural land, and commercial forests. If carbon emissions affect the productivity of these systems, one can estimate the cost as the lost market output. Likewise, one can estimate the cost of defensive expenditures caused by CO2 emissions, such as higher dykes, storm protection and more air conditioning.

The bigger challenge is to estimate a monetary value for damage to the mostly unmanaged systems of the earth. An example would be a loss of arctic ice leading to extinction of a non-commercial species, such as the polar bear, or the destruction of a major ecosystem, like the Amazon rainforest. Because these values are not directly linked to market products, estimating

[1] Nordhaus, W., "An optimal transition path for controlling greenhouse gases," Science, Vol.258, Nov. 1992.

[2] Nordhaus, W., The Climate Casino: Risk, Uncertainty and Economics for a Warming World, Yale, 2013.

the monetary loss to humanity is fraught with uncertainty. Some uncertain values are simply omitted, which biases downwards the SCC estimate. For this reason, the US Environmental Protection Agency (EPA) qualifies its own SCC estimate with, "However, given current modelling and data limitations, it does not include all important damages."[3] And this leads Nordhaus to conclude, "So, if anything, the uncertainties point to a more rather than less forceful policy – and one starting sooner rather than later – to slow climate change."[4]

Another big challenge for the SCC is to estimate a monetary value for low probability, catastrophic outcomes whose probability increases as temperatures rise, examples being runaway methane release in the Arctic, collapse of the West Antarctic Ice Sheet, and reversal of the Gulf Stream. Marty Weitzman of Harvard has argued for a decade that SCC estimates need to somehow incorporate these potential harms ('known unknowns'), as well as somehow considering as-yet unimaginable outcomes ('unknown unknowns').[5] As noted below, some researchers have tried to incorporate into the SCC at least some values for known potential damages from the low probability, catastrophic outcomes which seriously concern scientists.

Estimates of the social cost of carbon

Some jurisdictions monitor the SCC estimates of the US EPA, which are updated on a regular basis to incorporate research advances – with the caveat noted above that the estimates are nonetheless biased downwards. The following table shows the range of SCC estimates (in real 2007 $US) for a 3% discount rate for the next 20 years. Note that in all cases, researchers show the SCC to rise over time. This presents an 'optimal path' that minimizes the costs and maximizes the benefits of reducing CO2 emissions. The diversity in estimates is due to a range of values for key assumptions: notabley the forecasts of CO2 concentrations in the absence of efforts to reduce emissions, the impacts of those concentrations on the global atmosphere-land-ocean system, and the costs of reducing emissions. The range gets even wider if one uses a 5% discount rate, which leads to very low SCC estimates in the present and future.

US EPA (2007 $US)	2015	2035
Lowest estimate	**$36**	**$55**
Highest estimate	**$105**	**$168**

Source: US EPA, 2016, http://www3.epa.gov/climatechange/EPAactivities/economics/scc.html

[3] US EPA, Social Cost of Carbon, 2016. http://www3.epa.gov/climatechange/EPAactivities/economics/scc.html
[4] Nordhaus, W., "Why the global warming skeptics are wrong." New York Review of Books, 2012
[5] Weitzman, M., "Fat-tailed uncertainty in the economics of catastrophic climate change," Review of Environmental Economics and Policy, 2011.

When assessing its proposed regulations, such as vehicle or coal plant standards, the US EPA uses a wide range of values for the SCC. It does not select a single value from which to make decisions. Rather it simply records how each level of regulation performs under the different SCC values, including values that it notes are likely to be strongly biased downwards as in the case of a 5% discount rate.

Aside from the EPA, some researchers have responded to the challenge of unincorporated effects by estimating, by some means, the potential costs and probabilities of catastrophic outcomes. The next table shows the latest estimates provided by Simon Dietz and Nicholas Stern of the London School of Economics, using the same model as Nordhaus, but with some inclusion of low probability, catastrophic outcomes.[6] (Note that these values are in 2015 $US, while the EPA estimates in the previous table are in 2007 $US.)

Dietz & Stern (2015 $US)	2015	2035
Lowest estimate	**$32**	**$82**
Highest estimate	**$103**	**$260**

Source: Dietz and Stern, 2015.

As both tables show, the SCC estimates in each year cover a wide range. This presents a dilemma for policy-makers who seek to internalize the SCC into private and public decision-making in their jurisdiction. Even if they recognize the great uncertainty, they need to pick one or a few values if they intend to 'internalize' the externality of CO2 emissions.

Carbon pricing and the social cost of carbon

Economists argue that the prices of fossil fuels should be increased by the SCC value according to the CO2 emissions from fossil fuels – 'carbon pricing'. To reflect their different carbon intensities, the price of coal per unit of energy would increase by more than that of oil, which would increase by more than that of natural gas.

Carbon pricing via carbon taxes

The simplest and most transparent method of carbon pricing is by levying a carbon tax on coal, oil and natural gas. Experts widely agree that British Columbia's carbon tax, implemented in 2008, is a model example because of its consistency and comprehensiveness.[7] It is applied to

[6] Dietz, S. and N. Stern, "Endogenous growth, convexity of damage, and climate risk: How Nordhaus' framework supports deep cuts in carbon emissions," The Economic Journal, 2015.
[7] Murray, B. and N. Rivers, "British Columbia's revenue-neutral carbon tax: a review of the latest 'grand experiment' in environmental policy." Energy Policy, 2015.

fossil fuel combustion in virtually all sectors of the economy. At $30, the tax increases the price of gasoline by 7 cents per litre, with comparable effects on the price of coal and natural gas.

While there are other jurisdictions around the world with carbon taxes, the tax level tends to vary within each jurisdiction in order to prevent significant cost increases for carbon-intensive, trade-exposed sectors. Thus, Alberta's intended carbon tax, to be applied in 2017, will be the same as BC's for gasoline used in vehicles, natural gas used in buildings, and natural gas and coal used in electricity generation, but will be lower on average for these fuels when used in oil sands production facilities, refineries and petrochemical plants.

In keeping with the economists' argument that the carbon price should rise over time, Alberta's tax is slated to grow 5% annually over the rate of inflation. BC's tax increased $5 annually from 2008 to 2012, but is currently frozen at $30.

Carbon pricing via tradable permit prices in cap-and-trade systems

A second method for carbon pricing is to establish a jurisdiction-wide cap on CO2 emissions, and then allocate tradable permits that each year sum to the level of the cap – called 'cap-and-trade.' The market price of the tradable permits has the same effect as a carbon tax. If gasoline retailers must purchase permits at $30 / tCO2 for the carbon content in their gasoline, they will pass on this extra cost to consumers at a rate of 7 cents per litre.

In the case of cap-and-trade, however, the carbon price is uncertain because it depends on the cost of CO2 emission reductions in all sectors of the economy, which are not precisely known by government when it sets the cap. To remove some of this uncertainty, many jurisdictions with cap-and-trade systems now set a minimum price for the permits. In the joint cap-and-trade system of Quebec and California, for example, the minimum price for permits purchased and sold in Quebec was $10 (Cdn) in 2013, and set to increase 5% annually plus inflation. As of 2015, the permit trading price in Quebec has never been more than a few dollars above the minimum price.

Ontario is slated to soon join the Quebec-California system.[8] If this occurs by 2018, explicit emissions pricing will be the norm in Canada. Of a current national population of 36 million, 22 million (Quebec and Ontario) will have a minimum carbon price of almost $15 /tCO2 (depending on the cap-and-trade permit market at that time) and 8.5 million (BC and Alberta) will have a carbon tax of $30 /tCO2.

Implicit carbon prices

Emissions pricing is but one policy option for reducing CO2 emissions. Governments can also regulate private industry or give explicit directions to state-owned corporations and various public agencies. This approach has led to far more CO2 emission reductions in Canada and most other jurisdictions concerned about GHG emissions.

The most significant climate policy in Canada thus far was Ontario's closure of its coal-fired power plants, which it achieved between 2004 and 2014. This one policy reduced annual CO2 emissions by 25 megatonnes (MT). In 2007, BC passed a 'clean electricity' requirement that

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[8] Manitoba's government has also expressed its intent to join Quebec and Ontario, although it has not yet progressed down this path to a significant extent.

forced BC Hydro to cancel contracts for two private coal-fired power plants and its own plans for a large natural gas plant, reducing expected annual CO2 emissions in 2020 by 11-17 MT. In comparison, BC's carbon tax is estimated to reduce 2020 annual emissions by 3-5 MT.

From regulations and investment directives like these it is possible to calculate an 'implicit carbon price.' This is the carbon price that would be required to cause the same amount of emissions reduction in the sector in question. For example, it has been calculated that BC's electricity regulation had an implicit carbon price of $90 to $210 /tCO2, depending on assumptions of the cost of energy storage (for wind and run-of-river power) and natural gas in the future.[9] Crude estimates of Ontario's coal phase-out policy suggest that its implicit carbon cost was $100 to $150 /tCO2. Also, the Saskatchewan government subsidized the installation of carbon capture and storage technology at its Boundary Dam coal-fired power plant, and the cost has been estimated at more than $100 /tCO2 reduced, which may be acceptable since there may be future benefits from the development of this new technology. Finally, in announcing its new climate policy, Alberta noted that in addition to implementing a $30 carbon tax it would require an accelerated reduction in coal-fired power, which would include payments for wind power up to an implicit carbon price of $90 /tCO2.[10]

Social cost of carbon as a guide to regulations and investments

The following table summarizes the evidence on explicit and implicit carbon pricing in Canada. It shows, firstly, that real-world explicit carbon prices are either below estimated SCC values, or at least not slated to rise at the rate that would track them into the future. Secondly, it shows that seemingly high, real-world implicit carbon prices, resulting from regulations and public investment decisions, are much closer to the estimated SCC values into the future, given that these decisions about electricity generation investment are multi-decade commitments.

2018 carbon price ($ / tCO2)	Explicit carbon price	Implicit carbon price
Quebec	**≈$15**	**?**
Ontario	**≈$15**	**$100-$150 (coal plant phase-out)**
BC	**$30**	**$90-$210 (clean electricity requirement)**
Alberta	**$30**	**$90 (coal plants to wind)**

[9] Rhodes, K. and M. Jaccard, "A tale of two climate policies: political economy of British Columbia's carbon tax and clean electricity standard." Canadian Public Policy, 2013.
[10] Government of Alberta, "Climate Leadership Plan," 2015.

It is uncertain if estimates of the SCC guided any of the explicit or implicit pricing policies recently applied by Canadian provinces. Some research suggests that political acceptability is the most important factor in determining the type and stringency of climate policy.[11] This may explain why Canadian implicit prices exceed explicit prices. The cost of the carbon tax in BC is obvious to everyone who buys gasoline, since it is indicated on the pumps, whereas only an energy analyst would know the much higher cost of the clean electricity requirement. Thus, politicians who sincerely want to reduce CO2 emissions seem willing to use both the explicit and the implicit carbon pricing methods, but the latter has been applied at higher levels that might be more consistent with current estimates of the SCC trajectory over the next couple of decades.

The use of the SCC to guide policies in the US, at least at the federal level, is more direct and transparent. The EPA must show that any of its regulations pass a cost-benefit test, which includes monetized values for all externalities. Thus, the EPA value for the SCC was used in the latest EPA revisions to US vehicle efficiency and emissions regulations. Likewise, the EPA's new proposed coal plant emission regulation – currently in the comment and review phase – is justified in a cost-benefit analysis that uses the SCC estimate.

Thus, the SCC can provide a 'shadow price' for determining the stringency of government regulations. It can also be used by industry. Many corporations claim that they use an internal 'shadow price' for CO2 emissions in determining the level of energy efficiency and fuel choice in large and small investments.

Informing energy-climate policy in the Yukon

Over the next few years, as part of Canada's federal-provincial climate policy collaboration, the Yukon government might choose to implement a carbon tax, as in BC and soon Alberta, or a cap-and-trade system, as in Quebec and soon Ontario. But, regardless of this decision, the Yukon Energy Corporation has the immediate opportunity to apply a shadow carbon price to guide its investment and operation decisions, decisions that may have carbon emission implications for years and even decades to come.

The challenge is to decide which price to use as its shadow carbon price. Yukon Energy could test any decision against the range of EPA estimates for the SCC. But this range is so wide that it is not that helpful. Yukon Energy could take a precautionary approach, using the EPA's highest SCC values. Or it could be guided by the carbon prices that are explicit or implicit in decisions and policies in other Canadian jurisdictions.

If Yukon Energy were to use the explicit carbon price in other parts of Canada as a guide, the carbon prices in Quebec, Ontario, Alberta and BC will range from $15 to $30 in 2018, rising thereafter. These explicit prices are at the low end of EPA and more recent estimates of the SCC. But the benefit is that they will be applied to almost all CO2 emissions in these provinces, not just the emissions and investment decisions of public corporations and agencies. And all of these

[11] Rhodes, K., Axsen, J. and M. Jaccard, "Does effective climate policy require well-informed citizen support?" Global Environmental Change, 2014.

jurisdictions, with the exception of BC, have scheduled their carbon prices to rise annually.

If Yukon Energy were to use the implicit carbon prices in other parts of Canada as a guide, crown corporations and provincial governments in Ontario, BC, Saskatchewan and soon Alberta are accepting much higher prices to guide energy-related investment and planning, and in setting regulations that affect private investment decisions in renewable electricity generation. Thus, it would be consistent with these other jurisdictions for Yukon Energy to use a value in the neighbourhood of $100 /tCO2. This price reflects government decisions as diverse as Saskatchewan Power's investment in carbon capture and storage, Ontario Power's closure of its coal plants and replacement with low- and zero-emission alternatives, the BC government's clean electricity regulation favouring renewable electricity, and Alberta's recent policy announcement for wind to play a significant role in the accelerated closure of its coal plants.