Carbon Pricing Costs for Households and Revenue Recycling Options in Canada†

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Abstract

The Government of Canada's implementation of the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) mandates a floor price on greenhouse gas emissions in all provinces and territories in Canada. We quantify the costs of carbon pricing for households in each province and across the income distribution, and analyse revenue-recycling options based on existing provincial policies (where appropriate) as well as alternative revenue recycling options. Specifically, we quantify both direct and indirect costs for households, and using revenue-recycling policies, identify the net costs to households. To do this, we construct estimates of average household energy use (electricity, natural gas, gasoline and home heating oil) by province and income quintile. Our methodological approach to including indirect costs allows us to investigate the effect of complementary policies — such as the federal output-based pricing system for large emitters — in mitigating costs to households. We then use Statistics Canada's Social Policy Simulation Database and Model (SPSD/M) to analyse revenue recycling options.

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1 Introduction

The Government of Canada's implementation of the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) mandating a floor price on greenhouse gas emissions means that in 2019, all provinces and territories in Canada will have a carbon price. However, the implementation of carbon pricing in Canada is politically fraught. Several provinces have successfully implemented carbon pricing, others have announced plans in compliance with the PCF and have then retracted those plans, while others are refusing to implement carbon pricing. As an evolving policy area, there is little research produced on the expected or observed effects of carbon pricing in Canada, particularly when it comes to the costs to households.

The politicized nature of carbon pricing discussions in Canada mean there are both misleading estimates of costs to households and a limited understanding of the true expected costs. For example, in the recent New Brunswick election, the Progressive Conservative Party's estimates were $1200 for a family (Poitras, 2018). Our preliminary work suggests this estimate is overly high in addition to not considering revenue recycling (Winter, 2017, 2018b). Estimates by the Canadian Taxpayers Federation rely on multiplying total Canadian emissions by the per-tonne price, and then dividing by the number of households (Bowes, 2016), which is an overly simplistic and inaccurate approach. Given the political prominence and importance of this issue, it is imperative to develop careful estimates of the costs and benefits of carbon pricing and options for revenue recycling. Canadian academics and think-tanks have developed household cost estimates (Rivers, 2012; Tombe, 2016; Tombe and Rivers, 2017; Sawyer, 2018; Winter, 2018b), but detailed and comprehensive peer-reviewed academic work is outstanding. We fill this gap.

There is some extant research of the impacts of carbon pricing on Canadian households. Rivers (2012) examines the potential distributional burden of carbon pricing, but does not examine specific options for revenue recycling. Parry and Mylonas (2018) present a first-order incidence analysis for selected provinces. Closest to our work, Cameron (2018) and Sawyer (2018) explore the cost impacts and distributional consequences of the federal backstop — along with several revenue-recycling options — on households in Alberta, Saskatchewan and Ontario. Existing research on the effects of B.C.'s carbon tax (Rivers and Schaufele, 2014; Beck et al., 2015; Murray and Rivers, 2015; Yamazaki, 2017), as well as ex ante modelling of the potential effects of proposed carbon pricing schemes in other provinces (Böhringer et al., 2015; Carbone and Rivers, 2017), is helpful in suggesting policy impacts on households. However, comprehensive ex ante analysis that is specific to Canada — including each province and across the income distribution — is still outstanding. Most importantly, the majority of the existing research assesses B.C.'s carbon tax after the fact, and cannot necessarily be generalized to other provinces. This is particularly true when considering indirect costs, which depend on each province's built environment, industrial profile and trade patterns. Definitive analysis on the distributional impact of carbon pricing in Canada is still outstanding.

Our research quantifies the costs of carbon pricing for households in each province and across the income distribution, and analyses revenue-recycling options based on existing provincial policies (where appropriate) as well as alternative revenue recycling policies. Specifically, we quantify both direct and indirect costs for households, and using revenue-recycling policies, identify the net costs to households. To do this, we also construct estimates of average household energy use (electricity, natural gas, gasoline and home heating oil) by province and income quintile. Our methodological approach to including indirect costs also allows us to investigate the effect of complementary policies — such as the federal output-based pricing system for large emitters — in mitigating costs to households. In developing this work, we pursue four distinct but related research questions, building on the work of Winter (2017, 2018a), Fellows and Dobson (2017) and Dobson and Fellows (2017). First, what are the energy use patterns of Canadian households, the corresponding expected direct effects of carbon pricing, and how do these effects differ across Canadian provinces and income quintiles? Second, what are the expenditures patterns of Canadian households and the corresponding indirect effects of carbon pricing, and how do these effects differ across provinces and income quintiles? Third, what are revenue recycling options to mitigate costs to households and improve the durability and acceptability of carbon pricing policies? Fourth, how do assumptions about energy efficiency, energy use, and behavioural responses affect estimates of carbon pricing costs? Relatedly, what is the role of complementary support policies for businesses in mitigating costs to households?

We next describe our methodology for estimating direct costs and indirect costs, our construction of revenue estimates, and the revenue recycling policy experiments we explore. In the third section, we present results for the provinces of Alberta, Saskatchewan, Manitoba, Ontario, New Brunswick, Nova Scotia and Price Edward Island. We first document our estimates of carbon pricing costs across income quintiles, then explore revenue recycling scenarios for each province in turn. We also explore the role of the federal output-based pricing system for large emitters in mitigating costs to households. We end with brief conclusions from the preliminary results.

2 Methodology

We estimate costs to the average household in each province based on 2015 energy use patterns. This approach builds on Winter (2017). We deliberately adopt a 'worst case scenario' approach to measuring carbon pricing costs. We assume no behavioural change in response to the implementation of carbon pricing, and do not account for improvements in the energy efficiency of household appliances. We use this approach to provide a first-order estimate of potential revenues from household emissions derived from energy use.

The naive approach to calculating average household costs is to take total provincial emissions attributed to the residential sector and divide by the number of households, then multiply by the level of the carbon price. However, this approach ignores that different household energy sources have different emissions intensities, and that households differ in their energy use.

Canadian household energy use can be classified into three broad types: electricity, fuel for personal transportation (primarily gasoline and diesel), and natural gas and heating oil. There are other sources, but they are a small proportion of overall household energy use. The impact of carbon pricing on Canadian households will depend on the types of energy used by each household (for example, whether a household uses electricity, natural gas or heating oil for home heating), the emissions intensity of electricity in each province, and additional policies put in place by provincial governments to mitigate impacts.

Table 1 displays Canadian household energy use, by province in 2015, reporting GJ per household for each energy source, as well as the share of households using each of electricity, heating oil and natural gas. Notably, all households use electricity, but some use heating oil or natural gas for home heating. This emphasizes the importance of accounting for differences in household energy use in constructing carbon tax costs.

2.1 Average Household Direct Costs

We construct 'average' household energy use and emissions in each province, taking into account differences in the built environment faces by households, using data from Natural Resources Canada's Comprehensive Energy Use Database (CEUD).

We first construct total energy use estimates in natural units and emissions estimates in tonnes of CO_2e by end use for each province. The CEUD reports both energy use and emissions for each type of residential energy end-use. The exception is electricity (only energy use is reported), and so we construct emissions from electricity use from the 2015 production-weighted emissions intensity of each province's

Table 1: 2015 Household Energy Use (GJ) by Province

		Electricity	Heating Oil	Natural Gas	Transportation Fuels	Average Household Use (all energy types)
BC	GJ/Household	31.6	3.8	51	56	142
	Share of Households	100%	2%	63%	N/A	
AB	GJ/Household	24.8	0	100.3	70	195
	Share of Households	100%	0%	93%	N/A	
SK	GJ/Household	30.8	0	88.7	109	229
	Share of Households	100%	2%	91%	N/A	
MB	GJ/Household	51.9	0	81.7	88	221
	Share of Households	100%	3%	66%	N/A	
ON	GJ/Household	31.2	67.9	90.8	80	270
	Share of Households	100%	3%	75%	N/A	
QC	GJ/Household	67.2	22.9	60	64	214
	Share of Households	100%	7%	8%	N/A	
NB	GJ/Household	65.3	89.7	0	79	234
	Share of Households	100%	13%	0%	N/A	
NS	GJ/Household	39.3	93.7	0	85	218
	Share of Households	100%	48%	0%	N/A	
PE	GJ/Household	39.1	84.9	0	96	220
	Share of Households	100%	78%	0%	N/A	
NL	GJ/Household	64.3	98	0	110	272
	Share of Households	100%	19%	0%	N/A	

Source: Statistics Canada. Household energy consumption, Canada and provinces, Table: 25-10-0060-01; and Natural Resources Canada, Comprehensive Energy Use Database.

electric grid. We then construct weighted average energy use and emissions by energy end use. Finally, we divide these weighted averages by the total number of households, and sum over energy end use to construct final per household energy use and emissions estimates. We use total emissions to estimate direct revenues from households.

We rely on the following energy use categories to construct our energy use and emissions estimates: space heating, water heating, appliances, lighting, space cooling and passenger road transportation. For each use category, we construct weighted average energy use, where the weights are the proportion of each energy source's presence in the housing stock. As an example, consider space heating. Residential space heating in Saskatchewan in 2015 included the following heating system types: electricity, natural gas, heating oil, wood, and other (coal and propane). Average Saskatchewan residential heating energy use is then:

$$EU_{heat} = EU_{heat}^{elec} * \frac{HS_{elec}}{HS_{total}} + EU_{heat}^{NG} * \frac{HS_{NG}}{HS_{total}} + EU_{heat}^{HO} * \frac{HS_{HO}}{HS_{total}} + EU_{heat}^{wood} * \frac{HS_{wood}}{HS_{total}} \tag{1}$$

where NG is natural gas, HO is heating oil, HS is heating system stock, and EU is energy use. We use an identical approach to construct weighted-average emissions from residential heating, except we replace energy use with emissions from the energy use in the above.

2.2 Direct Costs Across the Income Distribution

The second aspect of our approach to constructing carbon tax costs relies on imputing average energy use by income group and by province. Our preferred approach relies on Statistics Canada Table 11-10-0223-01, which reports Survey of Household Spending aggregate expenditure on electricity, natural gas, and other fuel for principal accommodation as well as gas and other fuels used for private transportation by income quintile and province.[1] While expenditure data requires manipulation in order to back out estimates of energy consumption, this manipulation is relatively straightforward. It requires collecting energy prices, making adjustments for fixed costs (such as distribution charges for natural gas or electricity), and adjustments for tax rates. This is all publicly available information and so the difficultly comes from collecting the requisite price information rather than any calculations. The data from Table 11-10-0223-01 is also subject to few data suppressions, meaning it is possible to estimate energy use across income quintiles for all provinces with few additional assumptions. With energy use data in hand, it is straightforward to calculate direct household carbon tax costs. This also allows us to calculate expected

[1]We intend to expand this analysis to microdata from the Survey of Household Spending (SHS).

carbon pricing revenues, which feeds into our analysis of revenue recycling policies.

Specifically, we impute energy use (use) of type j in year t as follows:

$$use_{j,t} = \left(\frac{exp_{j,t}}{1+\tau} - f_{j,t} \right) / c_{j,t} \tag{2}$$

where exp is expenditure on energy, τ is taxes, f is fixed costs, and c is the variable cost of energy purchased by consumers.

One of the challenges we face in constructing energy use estimates from expenditure data is that in many provinces, households have choices in their utility providers. These utility providers differ in the fixed costs added to bills and the price of energy, as well as location of service. We adjust for these differences by constructing weighted-average energy prices and weighted-average fixed costs, where the weights are each firm's share of production or sales in its province, or regions within a province as appropriate.

A second challenge we face is the expenditure data on energy within income quintiles is the average expenditure for each quintile. This poses a challenge in that some households have utilities included in their rent, meaning average expenditure on energy is biased downwards, and so our estimates of energy use are also biased downwards. However, the emissions associated with utilities included in rent appear within our calculations of the indirect carbon costs faced by household (see the next section).[2]

Once we have converted expenditures on energy into consumption of energy in energy units (e.g. GJ, kWh), we multiply by the cost of carbon. In our scenarios we focus on the federal government's 2019 benchmark carbon price of \$20 per tonne CO2e. At this price, the carbon cost of gasoline is \$.0442 per litre and the carbon cost of natural gas is \$1.048257 per GJ (Department of Finance, 2018), and the carbon cost of electricity is determined by the emissions intensity of the provincial grid, detailed below.

2.3 Indirect Costs

To estimate indirect costs, we adapt the consumption-based greenhouse gas (GHG) accounting model developed in Fellows and Dobson (2017). The model calculates the emissions embodied in final consumption goods by tracking value shares through the entire Canadian economy. It does this using a multi-province, multi-sector input-output matrix derived from Statistics Canada's Provincial Symmetric Input-Output Tables (Catalogue 15-211-XCE).

[2] When calculating average natural gas usage in Alberta's lowest income quintile we arrive at an estimate of zero energy consumption. Since this is unlikely to hold we interpolate direct natural gas consumption in this quintile to be the midpoint between zero and the natural gas usage of the second-lowest income quintile.

The approach is similar to a conventional input-output (IO) model. However, where a typical IO model defines multipliers for productive inputs like labour, in this application the model defines multipliers for emissions. This is done by essentially substituting a vector of direct emissions (at the province-by-sector level) into a typical inter-regional IO model where there would conventionally be a vector of factors of production (labour). Using this approach, Fellows and Dobson (2017) produce multipliers relating the generation of all upstream emissions (direct and indirect) generated by the production of final goods in each province-sector pair.

To calculate indirect costs from carbon pricing to households, we modify this approach further, replacing the vector of direct emissions with a vector of net priced emissions, adjusting for the deferred carbon tax payments defined under the output based pricing system. The result is a new set of multipliers which relate the generation of upstream net priced emissions (a subset of total upstream emissions) to the production of final goods for each province-sector pair. We model the federal output-based pricing system for simplicity.

These multipliers in effect are equivalent to the priced-emissions intensity of final goods produced by each province-sector pair. As such, we can map these intensities onto provincial household expenditures and expenditure categories by quintile using Statistics Canada Table 11-10-0223. The end result is a dataset encompassing the net-priced emissions (adjusting for the output based pricing system) embodied in households' consumption by quintile and province.

As with our calculation of direct costs, our indirect carbon cost estimates are of the 'worst-case' variety since we assume full pass-through of carbon pricing costs from businesses to households. This means that our indirect costs are an upper bound on potential household indirect carbon costs.

2.4 Total Household Carbon Costs

We calculate average total household carbon costs within each quintile by adding direct and indirect carbon costs. To calculate total household cost per province we multiply the number of households within each quintile by the average total carbon cost within that quintile. Household counts per quintile are extracted from the Statistics Canada Social Policy Simulation Database/Model (SPSD/M).

2.5 Available Revenue

We are interested in comparing the distributional impacts of methods of spending carbon pricing revenues. We refer to these scenarios generally as "revenue recycling options". To calibrate various revenue recycling options we estimate the revenue that is available for recycling in each province. This calculation differs from total household cost because it accounts for carbon tax revenue raised through the export of products to other Canadian provinces (see Appendix A.1.1 for a detailed explanation). For example, Alberta is a net exporter of embodied emissions to the rest of Canada; the carbon tax costs paid upstream on oil and gas products sold to British Columbia are collected within Alberta and can be spent within Alberta. This means that Alberta's available carbon pricing revenue exceeds total household carbon costs in the province. Ontario, on the other hand, is a net importer of embodied emissions and its available carbon pricing revenues are less than total household carbon costs within the province.

Direct carbon costs remain the same for natural gas an transportation fuels when calculating available revenue since they are paid within each province. Direct costs associated with household electricity consumption are mitigated by the presence of output-based allocations, which lowers the average cost of emissions associated with electricity production.[3] We use the Fellows and Dobson (2017) model to calculate available revenue associated with embodied indirect carbon tax costs.

We calculate available revenue under two scenarios. First, we account for the existing OBPS policy. This policy means that only emissions released above a certain threshold are priced. Second, we estimate available revenue in a scenario without output-based allocations of free permits. This second scenario leads to higher direct and indirect carbon costs for households, and a greater amount of available revenue for recycling.

2.6 Revenue Recycling Options

After calculating total household carbon tax costs and available carbon tax revenues for each province, we analyse revenue recycling options using Statistics Canada's Social Policy Simulation Database and Model (SPSD/M). The SPSD/M is a static microsimulation model for analyzing the distributional impacts of government tax and expenditure policy. It contains rich microdata at the individual and household level and detailed representations of existing federal and provincial taxation and fiscal policy. Using the SPSD/M we explore the distributional impacts of four primary revenue-recycling approaches. The first is lump-sum rebates to all households, based on revenues raised from households. In particular, we model variants of the federal government's 'climate action incentive', a lump-sum means of recycling carbon pricing revenues in provinces subject to the federal government's carbon pricing backstop policy. The second is changes to personal income taxes, via increasing the provincial basic personal exemption. The

[3] As we assume full pass-through of costs from firms to households, we also assume full pass-through of the 'benefits' of OBAs to households.

third approach we simulate is changes to sales taxes (where applicable). The fourth is means-tested rebates, such as Alberta's means-tested climate rebate to lower-income households, Saskatchewan's low-income tax credit, and the federal government's GST tax credit.

3 Results

3.1 Household Carbon Costs

Household carbon costs vary by province and by income quintile. Figure 1 summarizes costs by cost source, province and income quintile, for seven Canadian provinces with carbon pricing.[4] Households in Alberta and Saskatchewan have higher carbon costs than households in other provinces. Much of the difference comes from relatively high greenhouse gas (GHG) emissions intensity electricity in the two prairie provinces. This high emissions intensity leads to higher direct electricity carbon costs and much higher indirect carbon costs, as businesses must pass along higher electricity-related carbon costs throughout the supply chain. A second source of higher costs in Alberta and Saskatchewan is higher transportation fuel use and natural gas use. As well, the exemption of home heating oil from carbon pricing in Atlantic Canada also reduces costs to those provinces.

In general, household carbon costs increase with income. On average, higher income households use more gasoline, natural gas and electricity than households in lower income quintiles. They also use their higher incomes to purchase more goods and services, which increases their indirect household carbon costs. The absence of an output-based pricing system (shown in 2) significantly increases estimated indirect costs to households.

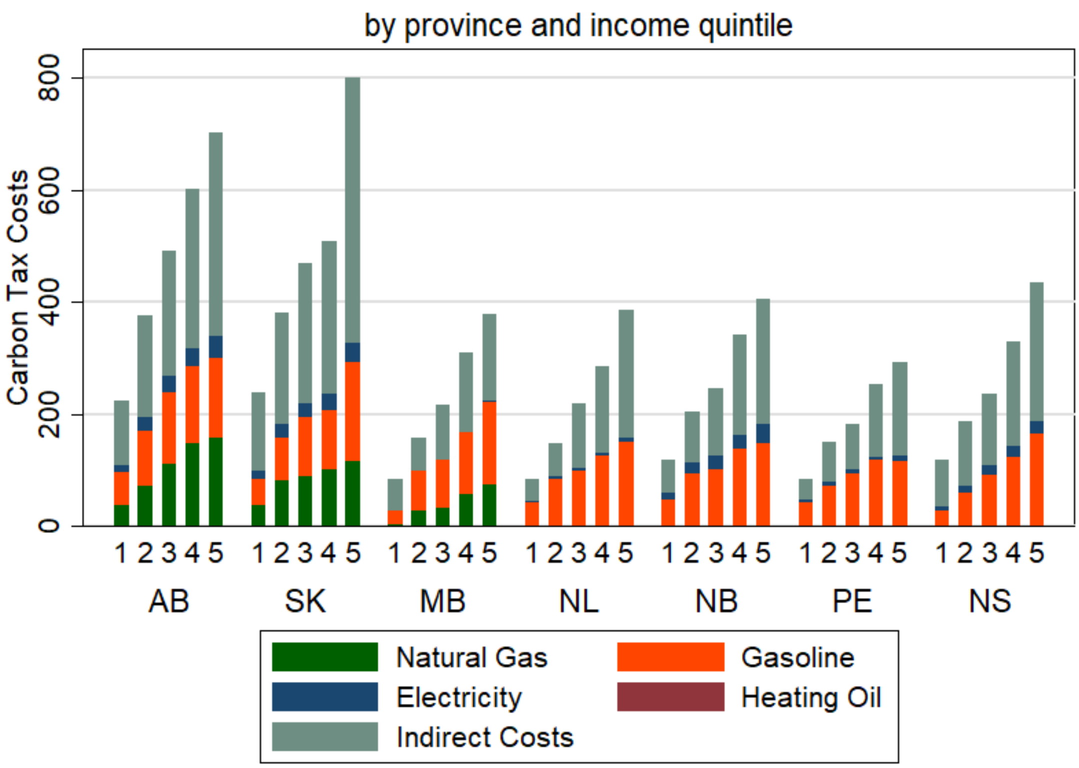
Our calculations of household carbon costs are of a similar magnitude to estimates by the Government of Canada. Environment and Climate Change Canada (ECCC) estimated an average household carbon cost of $403 for Saskatchewan in 2019 and our estimate is $468 for the middle-income quintile (Environment and Climate Change Canada, 2018). Part of the difference may be because ECCC accounted for the Saskatchewan's own OBPS system, while we calculate our costs assuming the federal OBPS system.

3.2 Revenue Recycling Scenarios

We compare different revenue recyling scenarios across provinces. As each province has different households energy use patterns, carbpn tax costs and revenues differ across provinces, meaning net rebates will

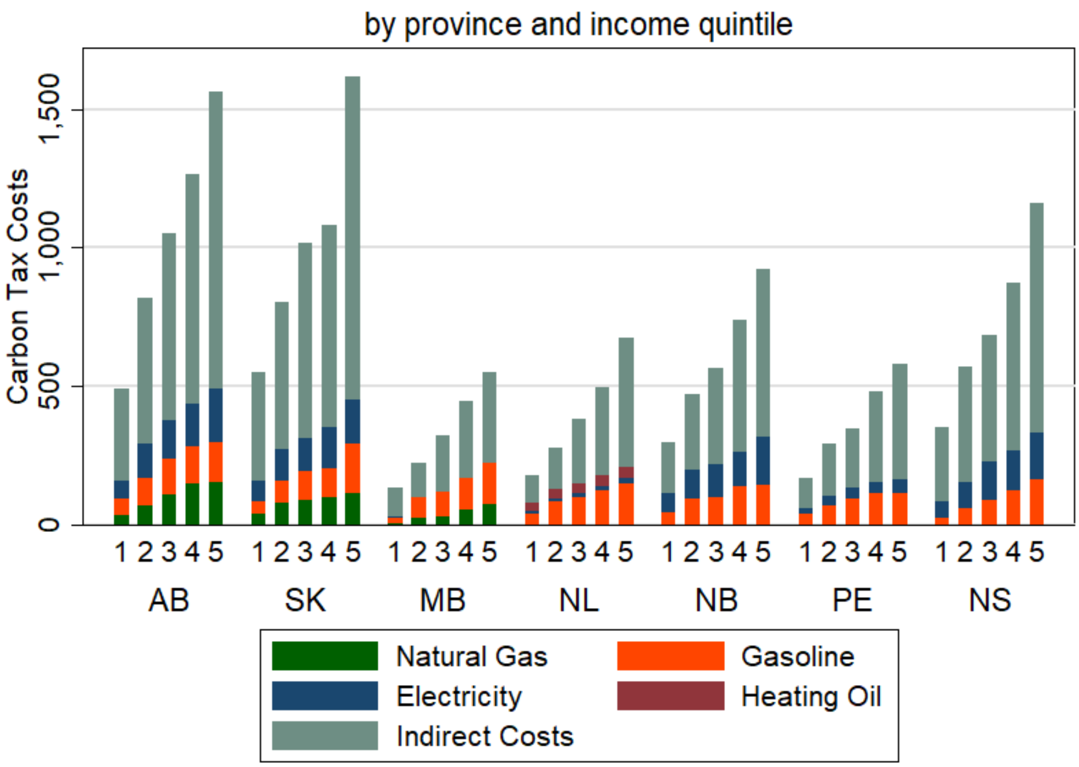
[4]We model actual policies, and include heating oil exemptions in Atlantic Canada.

Figure 1: Household Carbon Costs by Source, Province and Income Quintile



Note: Based on 2015 energy use. Assumes carbon price of $20 per tonne. Includes adjustments through output-based pricing systems, and heating fuel oil exemptions in Atlantic Canada. Income quintile 1 corresponds to the lowest quintile, while quintile 5 corresponds to the highest income quintile. Household counts and income thresholds differ by province.

Figure 2: Household Carbon Costs by Source, Province and Income Quintile

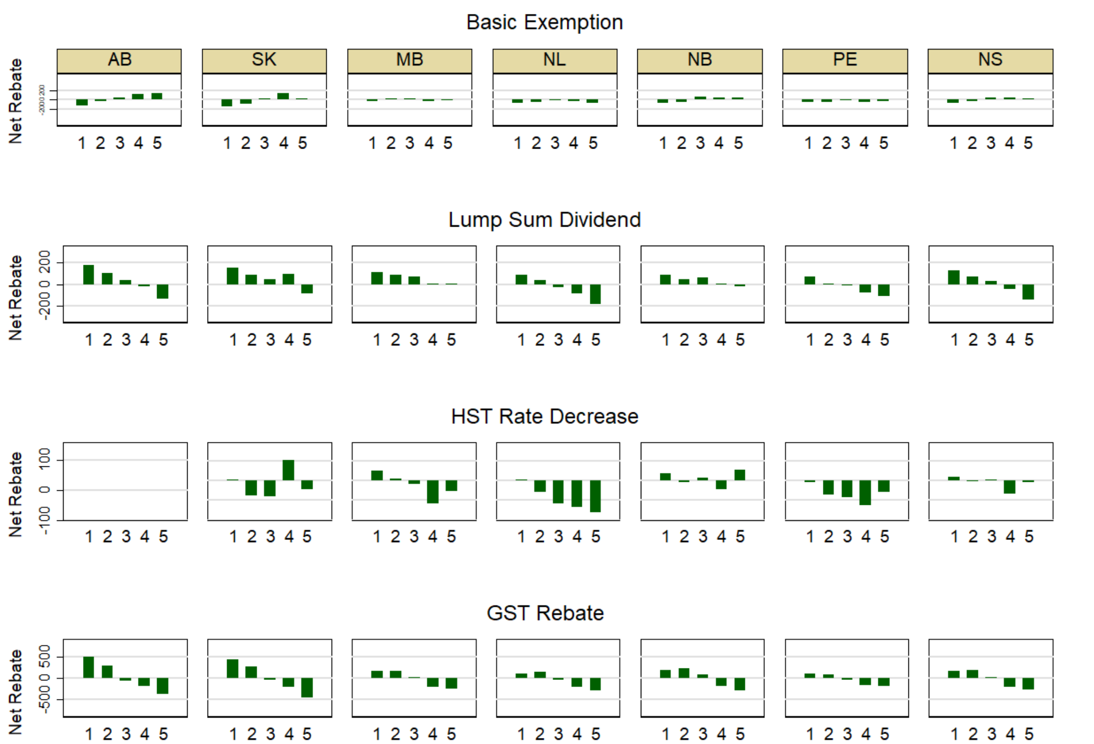


Note: Based on 2015 energy use. Assumes carbon price of $20 per tonne. Includes heating fuel oil exemptions in Atlantic Canada, except for Newfoundland and Labrador. Does not include adjustments from output-based pricing system. Income quintile 1 corresponds to the lowest quintile, while quintile 5 corresponds to the highest income quintile. Household counts and income thresholds differ by province.

also differ across provinces. The four scenarios we compare are (1) an HST tax rate reduction; (2) an increased basic exemption; (3) a GST rebate; and (4) a lump sum dividend. The net rebates are plotted in 3, and the full results are presented in Table 2. For all scenarios, we match expenditure to expected revenue within each province.

The general pattern across the provinces is that, as expected, increasing the income tax basic exemption is regressive and lump sum dividends and the GST rebate are progressive. The HST tax-rate decrease is progressive for Newfoundland and Labrador as well as PEI, but has no clear pattern for other provinces. Interestingly, the increased basic exemption, while generally has negative net rebates, is the closest to zero net impact on households (the average net rebate across all quintiles and provinces is -$10).

Figure 3: Net Rebates, by Province and Income Quintile under Different Revenue Recycling Scenarios



Note: Based on 2015 energy use. Assumes carbon price of $20 per tonne. Includes adjustments through output-based pricing systems, and heating fuel oil exemptions in Atlantic Canada. Income quintile 1 corresponds to the lowest quintile, while quintile 5 corresponds to the highest income quintile. Household counts and income thresholds differ by province.

Table 2: Carbon Tax Costs ($20 per tonne) and Average Net Rebates by Province and Income Quintile

			Revenue Recycling Scenarios									
			HST Tax Rate Dec.		Increased Basic Exemption		GST Rebate		Lump Sum Dividend		Alberta Dividend	
province	quintile	Total Costs	Rebate	Net Rebate	Rebate	Net Rebate	Rebate	Net Rebate	Rebate	Net Rebate	Rebate	Net Rebate
AB	Lower	223			100	-123	727	504	403	180	583	360
	Lower Middle	374			350	-25	677	302	482	107	596	221
	Middle	492			534	42	436	-56	529	37	597	105
	Upper Middle	601			727	126	415	-186	579	-22	422	-179
	Upper	703			839	136	329	-374	569	-134	352	-351
SK	Lower	238	240	2	84	-154	679	441	392	154		
	Lower Middle	380	342	-38	295	-85	645	265	471	91		
	Middle	468	427	-40	492	25	432	-36	512	44		
	Upper Middle	507	560	53	648	141	305	-202	600	93		
	Upper	800	778	-22	823	23	351	-449	713	-87		
MB	Lower	85	109	24	50	-34	263	179	195	110		
	Lower Middle	157	161	4	159	2	322	165	242	85		
	Middle	215	206	-9	236	21	213	-2	289	74		
	Upper Middle	308	250	-58	279	-29	113	-195	311	3		
	Upper	377	352	-26	359	-18	143	-235	387	9		
NL	Lower	85	85	1	15	-70	199	115	173	88		
	Lower Middle	147	117	-30	99	-48	290	143	189	41		
	Middle	218	159	-59	208	-10	181	-37	190	-28		
	Upper Middle	283	216	-67	256	-27	85	-198	196	-87		
	Upper	386	306	-80	312	-73	96	-290	199	-187		
NB	Lower	119	136	18	44	-75	311	193	204	85		
	Lower Middle	204	199	-5	147	-57	436	232	253	49		
	Middle	246	254	8	308	62	325	79	306	60		
	Upper Middle	342	321	-22	394	52	162	-180	338	-4		
	Upper	405	432	27	449	44	125	-280	387	-18		
PE	Lower	84	80	-4	34	-49	196	113	155	72		
	Lower Middle	150	115	-35	100	-49	248	99	159	9		
	Middle	183	141	-42	172	-11	157	-26	168	-15		
	Upper Middle	254	192	-62	201	-52	88	-165	175	-79		
	Upper	292	264	-28	266	-26	110	-182	183	-109		
NS	Lower	118	127	9	43	-75	294	177	245	127		
	Lower Middle	188	187	-1	159	-29	388	200	261	73		
	Middle	236	239	2	281	45	258	22	268	31		
	Upper Middle	328	294	-34	370	42	132	-196	281	-47		
	Upper	434	428	-5	448	14	164	-270	293	-141		

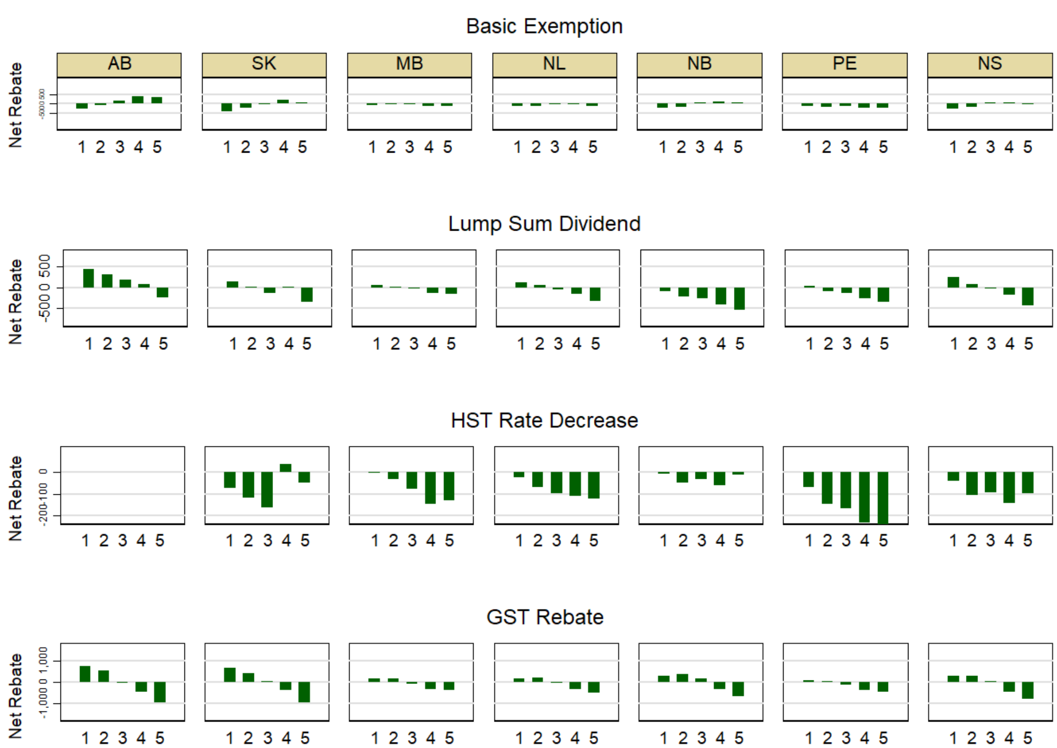
Note: Includes federal output-based pricing system.

3.3 Revenue Recycling Scenarios Without the Output Based Pricing System

As discussed above, the OBPS reduces the cost of carbon pricing for large final emitters, including the electricity sector. Because these carbon pricing costs are passed on to consumers, the OBPS system also reduces the cost of carbon pricing on consumers. In this section we present our analysis assuming full carbon pricing for all industries within Canada. We then scale our revenue recycling options based on the higher levels of available revenue that would result in the absence of output-based allocations. The net rebates are plotted in Figure 4, and full results are presented in Table 3.

Notably, net rebates have larger absolute values compared to net rebates with adjustments for the OBPS. This is of course because net costs are higher, but revenue is also higher and so rebates across the income distribution is are also larger. Recycling revenue via an increased basic exemption or the HST rate decrease are regressive. By contrast, the lump sum dividend and GST rebate recycling methods are progressive.

Figure 4: Net Rebates, by Province and Income Quintile under Different Revenue Recycling Scenarios, no OBPS



Note: Based on 2015 energy use. Assumes carbon price of $20 per tonne. Includes heating fuel oil exemptions in New Brunswick, PEI and Nova Scotia. while quintile 5 corresponds to the highest income quintile. Household counts and income thresholds differ by province.

Table 3: Carbon Tax Costs ($20 per tonne) and Average Net Rebates by Province and Income Quintile, No OBPS

			Revenue Recycling Scenarios									
			HST Rebate		Increased Basic Exemption		GST Rebate		Lump Sum Dividend		Alberta Dividend	
province	quintile	Total Costs	Rebate	Net Rebate	Rebate	Net Rebate	Rebate	Net Rebate	Rebate	Net Rebate	Rebate	Net Rebate
AB	Lower	491			207	-284	1230	739	945	454	1208	716
	Lower Middle	819			746	-73	1382	563	1130	311	1328	509
	Middle	1054			1205	151	1008	-46	1240	186	1366	312
	Upper Middle	1265			1656	391	826	-439	1358	93	1062	-203
	Upper	1563			1948	386	632	-931	1335	-227	823	-740
SK	Lower	551	479	-73	150	-401	1218	667	690	138		
	Lower Middle	805	686	-119	561	-244	1215	410	832	27		
	Middle	1018	856	-162	994	-24	1015	-3	897	-121		
	Upper Middle	1080	1120	40	1319	239	712	-368	1073	-7		
	Upper	1617	1569	-48	1703	86	697	-920	1277	-340		
MB	Lower	133	130	-3	59	-75	315	182	195	62		
	Lower Middle	223	193	-30	189	-34	390	167	242	19		
	Middle	321	246	-75	282	-39	263	-58	289	-32		
	Upper Middle	447	299	-147	335	-112	143	-304	311	-135		
	Upper	549	420	-129	430	-119	174	-375	387	-162		
NL	Lower	177	152	-24	26	-151	343	167	311	134		
	Lower Middle	279	211	-68	173	-106	504	225	338	59		
	Middle	384	286	-98	375	-9	355	-29	341	-43		
	Upper Middle	496	388	-108	461	-34	167	-328	351	-144		
	Upper	673	550	-123	563	-110	167	-506	358	-315		
NB	Lower	296	288	-8	82	-214	595	299	204	-92		
	Lower Middle	470	422	-48	291	-179	838	368	253	-217		
	Middle	565	535	-30	643	78	744	179	306	-259		
	Upper Middle	739	679	-60	844	105	407	-331	338	-401		
	Upper	920	911	-9	962	42	265	-655	387	-533		
PE	Lower	171	104	-66	45	-126	256	85	207	36		
	Lower Middle	294	150	-144	134	-160	323	29	213	-82		
	Middle	349	182	-167	230	-119	216	-133	225	-125		
	Upper Middle	483	249	-234	272	-211	123	-361	233	-250		
	Upper	583	344	-239	357	-226	143	-440	244	-338		
NS	Lower	355	317	-38	93	-262	660	305	607	252		
	Lower Middle	571	465	-106	387	-184	884	313	646	76		
	Middle	685	595	-91	702	17	731	46	663	-23		
	Upper Middle	871	730	-141	924	53	418	-453	697	-174		
	Upper	1162	1064	-99	1120	-42	389	-773	726	-436		

Note: Does not adjust for federal output-based pricing system. We assume full cost pass-though.

4 Conclusion

We find that the “use-side” impacts of carbon pricing on the costs of energy and the prices of goods and services would have a regressive impact on net consumable income for households in across Canada without revenue recycling. The revenue raised by carbon pricing creates opportunities to offset distributional impacts by recycling revenues. Our simulations show that increasing the basic income tax exemptions within each province does not undo the regressive nature of carbon pricing, but instead increase net consumable income for the average household in the highest income quintile(s). Cuts to provincial sales taxes in are well matched to offset the impact of carbon pricing when the OBPS is in place, but are unable to restore the purchasing power of low income households in the absence of the OBPS. Means-tested policies such as increases to the GST rebate is a progressive means of recycling carbon pricing revenues and leave the average household in the lowest income quintile(s) with higher levels of consumable income than without carbon pricing. Lump-sum rebates, as offered by the federal government under their backstop program are also progressive and can lead to small gains in consumable income for the average household in the lowest income quintiles, while largely offsetting carbon pricing costs for the middle income quintile and second highest income quintile.

We also find that the OBPS significantly dampens the impact of carbon pricing on households. Without the OBPS, revenue recycling options could be more generous, but the regressive or progressive nature of each option would be magnified.

In future research we will expand our analysis to estimate the “supply-side” impacts of carbon pricing. Using a computable general equilibrium (CGE) model, we will estimate the impacts of carbon pricing on wages and returns to capital, and include those impacts in a comprehensive analysis of the distributional impacts of carbon pricing.

A Appendix: Province-Specific Results

A.1 Results with Output-Based Pricing

A.1.1 Alberta

Total household carbon costs in Alberta would be up to $777 million in 2019 at a carbon price of $20 per tonne and with the federal OBPS in place. Without revenue recycling a carbon price would have a regressive impact on Alberta households. Households in the lowest income quintile would see net household income decline by 0.8%, while households in the highest income quintile would experience a decline of only 0.21% (see Figure 5 below). Of note, our analysis includes only the "use-side" impacts of carbon pricing related to how carbon pricing impacts the prices of goods and services. We do not estimate "supply-side" impacts of carbon pricing related to impacts on returns to labour and capital, which may lead to more progressive outcomes even without revenue recycling (see Goulder et al., 2019).

We calculate that Alberta would have up to $830 million dollars in available carbon pricing revenue in 2019. This means Alberta could more than compensate households for expenditures related to the provincial carbon price. The 6.5% in additional available carbon pricing revenue is related to purchases of Alberta goods and services made by out-of-province businesses (intermediate inputs to household goods) and households (final goods). We calibrate our revenue recycling options to spend the full $830 million within the household sector.

Alberta implemented a carbon pricing system in 2017. The system began with a carbon price of $20 per tonne CO2e and this price increased to $30 per tonne in 2018. As part of the Alberta climate plan, the province rebated some of the carbon pricing revenues back to households in the form of "carbon levy household rebates". These rebates were lump-sum payments to Alberta residents. They were also means-tested and were paid to single residents who earned less than $47,500 per year and families who earned less than $95,000 per year. The rebates were designed to ensure low-income households would not be unduly burdened by the provincial carbon price. Alberta used only a portion of its carbon pricing revenues for the rebates and used the rest for initiatives to further reduce GHG emissions. We analyse a scenario where the means-tested carbon levy is increased in magnitude. We find that Alberta could increase the existing household rebates by up to 1.75 times given the available revenue (see Figure 5 below). The result would be highly progressive. Households in the lowest income quintile would see net household "consumable income" increase by 1.3%.[5] Households in the second and third income quintiles

[5] Consumable income is a parameter within SPSD/M. It is defined as total income minus total income taxes and commodity taxes paid by households.

would also see net gains. Households in the top two income quintiles would pay more in direct and indirect carbon costs than they would receive in carbon levy rebates and their consumable income would decline by 0.13% and 0.11% respectively.[6]

Figure 5: Alberta Revenue Recycling Impact on Net Household Consumable Income

Income Quintile	Average Household Income	2019: No revenue recycling	2019: Alberta Carbon Levy Rebate 1.75x	2019: Increase Basic Exemption to $21,710	2019: Increase Federal GST Rebate by 2.6x	2019: Enhanced Federal Carbon Backstop
0 to 20 (lowest)	$27,726	-0.80%	1.30%	-0.44%	1.82%	0.65%
20 to 40	$59,923	-0.62%	0.37%	-0.04%	0.50%	0.18%
40 to 60	$92,959	-0.53%	0.11%	0.05%	-0.06%	0.04%
60 to 80	$139,841	-0.43%	-0.13%	0.09%	-0.13%	-0.02%
80 to 100 (highest)	$329,867	-0.21%	-0.11%	0.04%	-0.11%	-0.04%
Policy Cost ($Millions)		$0	$824	$831	$829	$831

Federal Carbon Backstop scaled for Alberta to $345.49 (first adult), $172.18 (second adult), $86.09 (child)
Basic Exemption refers to basic personal income tax exemption

Carbon pricing revenues could also be used to reduce income taxes. We find that an increase in the basic income tax exemption from $19,305.69 to $23,138.75 would result in a tax expenditure of $830.5 million. This approach to revenue recycling would lead to a regressive outcome at the household level. Households in the three highest income quintiles would see net gains to consumable income, while households in the lowest income quintile would see consumable income reduced by 0.44%.

In provinces subject to the federal carbon pricing backstop, the federal government recycles carbon pricing revenues by sending lump-sum rebates to individuals. Rebates are given to households based on family composition. For example, in Saskatchewan, the first adult in an economic family receives a rebate payment of $305, the second adult receives a payment of $152, and $72 is provided for each child under the age of 18 in the family. We model the cost of providing a federal carbon backstop payment system in Alberta by capturing household composition within quintiles from the SPSD/M.[7] We then scale the Saskatchewan payments for Alberta to equal a total expenditure of $831 million. In the table above we refer to this scenario as the 'Federal Carbon Backstop'. Payments to Alberta residents could equal

[6] Households in the highest income quintile may still receive carbon levy rebates due to the nature of household formation in SPSD/M. Households can be composed of individuals who qualify for the rebates in addition to other individuals or economic families who do not qualify for the rebates. Household income is the sum of all members of a household.

[7] The SPSD/M provides counts of households with children, but does not specify the number of children per household within each quintile. We assume that each household with children has 1.87 children, the average number of children per census family in Alberta according to Statistics Canada Table 39-10-0041-01.

$345.49 for the first adult in an economic family, $172.18 for the second adult, and $86.09 per child. This would result in a progressive outcome. Households in the lowest income quintile would have consumable income 0.65% higher than without carbon pricing, and only the two highest income quintiles would see a decrease in consumable income. Even then, the decrease is small in magnitude; only -0.02% for the second highest income quintile and 0.04% for the highest income quintile.

The last revenue recycling option for Alberta is a means-tested approach to recycling revenue. We increase the size of the federal GST rebate and calibrate the change to equal available revenue. We find that carbon pricing revenues could be used to increase GST rebate amounts by 2.6 times or 160%. The outcome of this change would be highly progressive. Households in the lowest income quintile would see consumable income increase by 1.82%, while households in the second lowest income quintile would see an increase of 0.5%. The results are similar to the existing Alberta carbon levy rebate, although households in the middle income quintile would see a net decline in consumable income under the increased GST rebate policy.

A.1.2 Ontario

We estimate total household carbon costs in Ontario to be $1.376 billion in 2019 at a carbon price of $20 per tonne and assuming full cost pass-through from businesses and no changes to behaviour or energy use in response to the carbon price. The revenue available for recycling in the province is lower because Ontario is a net importer of embodied carbon emissions and carbon costs. We estimate that Ontario could bring in up to $1.288 billion in 2019 and this revenue could be used to offset the impacts of carbon pricing on households. Because available revenue is lower than total household cost, it is not possible for revenue recycling to offset the entire impact of carbon pricing on households in Ontario.

The patterns we see in the Alberta results are echoed in the Ontario results. In general, an income tax cut in the form of an increase in the basic exemption amount leads to a regressive outcome. When the Ontario basic income tax exemption is increased from $10,568.91 to $14,261, only households in the highest income quintile see net consumable income increase, while households in the lowest income quintile see net consumable income decline by 0.48%.

As in the case of Alberta, an increase in the GST rebate would lead to progressive outcomes, increasing net consumable income for the two lowest income quintiles. With less available carbon pricing revenue per resident, and a relatively greater number of individuals qualifying for the GST rebate, Ontario could only increase the GST rebate by 66.5% (compared to the 160% increase possible in Alberta).

Figure 6: Ontario Revenue Recycling Impact on Net Household Consumable Income

Income Quintile	Average Household Income	2019				
		No revenue recycling	Cut Provincial portion of HST to 7.47%	Increase Basic Exemption to $14,261	Increase Federal GST Rebate by 1.665x	Federal Carbon Backstop
0 to 20 (lowest)	$20,331	-0.59%	-0.04%	-0.48%	0.71%	0.28%
20 to 40	$45,573	-0.40%	-0.05%	-0.14%	0.30%	0.10%
40 to 60	$72,480	-0.32%	-0.04%	-0.01%	-0.03%	0.05%
60 to 80	$107,194	-0.29%	-0.04%	-0.01%	-0.12%	0.00%
80 to 100 (highest)	$232,369	-0.17%	-0.01%	0.02%	-0.11%	-0.02%
Policy Cost ($Millions)		$0	$1,291	$1,285	$1,288	$1,517

Federal Carbon Backstop for Ontario $154 (first adult), $77 (second adult), $38 (child)

Basic Exemption refers to basic personal income tax exemption

Because the Ontario government has cancelled its cap-and-trade program it is now subject to the federal government's carbon pricing backstop. We calculate the distributional impact of the federal government's 'climate action incentive' rebates using SPSD/M. In the first year of the backstop these rebate amounts are set at $154 for the first adult in an economic family, $77 for the second adult, and $38 per child. The federal policy succeeds in making households within the first four income quintiles as good as or better off than they were before carbon pricing was introduced. Households in the highest income quintile see net consumable income decline by only 0.02%. This policy does, however, appear to require more revenue than would be collected from Ontario households' purchases. We find that the federal 'climate action incentive' rebates have a cost of $1.5 billion in 2019, which is over $200 million higher than available carbon pricing revenue within Ontario, and $130 million more than Ontario's total household carbon costs.

Ontario has a harmonized sales tax (HST) of 13%, of which 5% is levied by the federal government and 8% is levied by the provincial government. We find that Ontario could use its carbon pricing revenues to reduce its portion of the HST by half a percentage point. This would lead to a fairly equitable outcome in terms of proportional changes to net consumable income across the income distribution. The first four income quintiles would see net consumable income decline by between 0.04 and 0.05%, while the highest income quintile seeing a reduction in net consumable income of only 0.01%. Due to the shortfall of available carbon pricing revenues no income quintile is made better off or returned with this policy. It is however, the most equitable means of apportioning the impact of carbon pricing.

A.1.3 Saskatchewan

We estimate that total household carbon costs for Saskatchewan would be $213.3 million in 2019, subject to the assumptions listed for Alberta and Ontario. As a net exporter of embodied carbon costs (largely due to its export-oriented energy sector), Saskatchewan would have $217.3 million in available revenue in 2019 that it could use to offset the impacts of carbon pricing.

With lower average incomes than Alberta in the lowest income quintile, carbon pricing would have a greater proportional negative impact on this quintile within Saskatchewan. Without revenue recycling, the net consumable income of the average household in the lowest income quintile would decline by 1.15%. An increase in the basic income tax exemption from $16,065 to $19,643 would improve outcomes for the lowest income households somewhat, but would still leave those in the lowest income quintile with net consumable income 0.74% lower than prior to the introduction of carbon pricing. Households in the three highest income quintiles on the other hand would see net consumable income increase, especially those in the second highest income quintile.

Figure 7: Saskatchewan Revenue Recycling Impact on Net Household Consumable Income

		2019				
Income Quintile	**Average Household Income**	**No revenue recycling**	**Cut PST from 6% to 4.91%**	**Increase Basic Exemption to $19,643**	**Increase SLITC from $346 to $987**	**Federal Carbon Backstop**
0 to 20 (lowest)	$20,673	**-1.15%**	0.01%	-0.74%	2.13%	0.75%
20 to 40	$47,795	-0.80%	-0.08%	-0.18%	0.55%	0.19%
40 to 60	$80,164	-0.58%	-0.05%	0.03%	-0.05%	0.05%
60 to 80	$118,922	-0.43%	0.04%	0.12%	-0.17%	0.08%
80 to 100 (highest)	$230,487	-0.35%	-0.01%	0.01%	-0.19%	-0.04%
Policy Cost ($Millions)		$0	$210	$210	$210	$238

SLITC - Saskatchewan Low-Income Tax Credit

Basic Exemption refers to basic personal income tax exemption

Saskatchewan's provincial sales tax was increased from 5% to 6% in the 2017 budget. Carbon pricing revenues could be used to reverse this increase and would lead to relatively equitable changes to net consumable income within each income quintile. Due to the pattern of spending and saving within

Saskatchewan a PST cut to 4.91% would lead to higher net consumable incomes for average households in the lowest income quintile and the second highest quintile. Households in the second lowest income quintile would see a net decline in consumable income of 0.08%.

Saskatchewan has a means-tested rebate called the 'Saskatchewan Low-Income Tax Credit' (SLITC) that is aimed at reducing the impact of sales taxes on low-income households. The credit is a tax-free payment that is provided alongside GST tax credit payments. As a means-tested policy, the SLITC begins to be reduced when family net income reaches $32,643 and is reduced to zero when net family income reaches $67,697. We model an increase to the SLITC payment provided to the first adult of an economic family. We find that this payment could be increased from $346 to $987. Like the increase to the GST rebate modelled for Alberta and Ontario, an increase to the SLITC would be highly progressive, increasing net consumable income by 2.13% for the average household in the lowest income quintile.

While the Saskatchewan government has imposed a carbon price on large final emitters through its 'Prairie Resilience' plan, it has resisted imposing an economy-wide carbon price. Due to this position the federal government has implemented its carbon pricing backstop in the areas where a carbon price is absent within Saskatchewan. We model the federal government's 'climate action incentive' payments for Saskatchewan and find that the payments are a progressive means of redistributing carbon pricing revenues, and leave households within the first four income quintiles better off than they would be in the absence of carbon pricing. As was the case in Ontario, we also find that the cost of the federal incentive program is greater than the revenue available in Saskatchewan that can be traced to household final consumption. There is a $20 million gap between available revenue within Saskatchewan and the cost of the federal rebate.

A.2 Results without Output-Based Pricing

A.2.1 Alberta

In the absence of the OBPS, total household carbon costs in Alberta would more than double, increasing from $777 million to $1.68 billion. Alberta would remain a net exporter of embodied carbon costs, meaning that available revenue for recycling within the province would still be higher than total household costs, increasing from $831 million with the OBPS to $1.95 billion without the OBPS.

The higher incidence of carbon pricing costs in the absence of the OBPS exaggerates the impact of carbon pricing on household incomes. Without revenue recycling, consumable income would decline by 1.77% for the average household in the lowest income quintile, and by up to 0.47% for the highest income quintile.

Figure 8: Alberta Revenue Recycling Impact on Net Household Consumable Income (no OBPS)

Income Quintile	Average Household Income	2019 No revenue recycling	Alberta Carbon Levy Rebate 3.8x	Increase Basic Exemption to $28,990	Increase Federal GST Rebate by 4.32x	Federal Carbon Backstop 2.66x
0 to 20 (lowest)	$27,726	-1.77%	2.58%	-1.03%	2.66%	1.64%
20 to 40	$59,923	-1.37%	0.85%	-0.12%	0.94%	0.52%
40 to 60	$92,959	-1.13%	0.34%	0.16%	-0.05%	0.20%
60 to 80	$139,841	-0.90%	-0.15%	0.28%	-0.31%	0.07%
80 to 100 (highest)	$329,867	-0.47%	-0.22%	0.12%	-0.28%	-0.07%
Policy Cost ($Millions)		$0	$1,948	$1,944	$1,944	$1,949

Federal Carbon Backstop scaled for Alberta to $810.20 (first adult), $403.77 (second adult), $201.88 (child)

Basic Exemption refers to basic personal income tax exemption

Without the OBPS, policies to recycle revenue would have similar distributional implications as outlined above, but these distributional impacts would be magnified. The higher available carbon revenues could make means-tested policies such as the Alberta Carbon Levy Rebate and the federal GST rebate much more generous. To spend the $1.95 billion carbon pricing revenues, the Alberta Carbon Levy Rebate could be increased by 280%, while the federal GST rebate could be increased by 332%. In both cases, this would lead to gains in the net consumable income of the lowest income quintile of between 2.58 and 2.66%, while net consumable income for the highest income quintile would be reduced by 0.22 to 0.28%.

An increase to the basic income tax exemption would remain a regressive means of redistributing carbon pricing revenues. The average household in the lowest income quintile would see net consumable incomes decline by over 1%, while the top three income quintiles would see higher net consumable income.

With higher available carbon revenues, the federal government could increase the size of its lump-sum rebates. The federal carbon backstop 'climate action incentive' payments could be increased to $810.20 for the first adult in an economic family, $403.77 for the second adult, and $201.88 for each child. In this case, the average household in each of the four lowest income quintiles would have higher net consumable incomes, while the average household in the highest income quintile would have net consumable income 0.07% lower than without carbon pricing.

A.2.2 Saskatchewan

A similar story can be told for Saskatchewan. Without the OBPS, Saskatchewan becomes a net importer of embodied carbon costs. Without the OBPS, total household carbon costs in Saskatchewan more than double to $451 million, while available revenues would increase to $440 million in 2019.

Without revenue recycling measures, the dampening effect of the OBPS holds large benefits for Saskatchewan low-income households. Net consumable income for the average household in the lowest income quintile would decline by up to 2.67% without the OBPS and without revenue recycling, while only declining by 1.15% when the OBPS is in place.

With a higher carbon pricing burden, the alignment of a PST cut with carbon costs is reduced. While higher carbon revenues could allow Saskatchewan to cut PST by up to 2.27% without the OBPS, average households within the lowest three income quintiles still see substantial declines in net consumable income.

Figure 9: Saskatchewan Revenue Recycling Impact on Net Household Consumable Income (no OBPS)

Income Quintile	Average Household Income	2019				
		No revenue recycling	Cut PST from 6% to 3.73%	Increase Basic Exemption to $24,071	Increase SLITC from $346 to $1556	Federal Carbon Backstop 1.85x
0 to 20 (lowest)	$20,673	-2.67%	-0.35%	-1.94%	3.23%	0.67%
20 to 40	$47,795	-1.68%	-0.25%	-0.51%	0.86%	0.06%
40 to 60	$80,164	-1.27%	-0.20%	-0.03%	0.00%	-0.15%
60 to 80	$118,922	-0.91%	0.03%	0.20%	-0.31%	-0.01%
80 to 100 (highest)	$230,487	-0.70%	-0.02%	0.04%	-0.40%	-0.15%
Policy Cost ($Millions)		$0	$439	$440	$440	$440

SLITC - Saskatchewan Low-Income Tax Credit

Basic Exemption refers to basic personal income tax exemption

An increase to the basic income tax exemption would provide benefits to the top two income quintiles, but would leave the lowest income quintile with a reduction in net consumable income of 1.94%.

The basic amount awarded by the means-tested SLITC could be increased by over $1,000 without the OBPS. This would increase net consumable income for the average household in the lowest income quintile by 3.23%.

The federal carbon pricing backstop could be scaled upwards by 85%, which would lead to gains for the bottom two income quintiles, while reducing net consumable income by 0.01 to 0.15% in the highest three income quintiles.

B Technical Appendix: Indirect Intensity Calculation

The Fellows and Dobson (2017) model, which is the base for our calculation of indirect emissions, uses expenditure and revenue flows from provincial-level symmetric input-output tables (Statistics Canada, 2015b) to allocate GHG emissions across sectors and regions in a manner that reflects the emissions "embodied" in the output of each sector. In this application, the term "embodied" implies that the emissions being accounted for are all of the upstream emissions that occur as a result of output in every sector. The concept is similiar to the development of a conventional Input-Output multiplier, except that in this application the multiplier is constructed for emissions rather than an input factor (like labour employment) or a macroeconomic metric (like GDP).

In this appendix, we provide a mathematical description of the Fellows and Dobson (2017) model and describe modifications to it such that it can be applied to the calculation of indirect cost of emissions pricing to households by quintile and region in Canada. We proceed in two steps, first describing our modified version of the Fellows and Dobson (2017) model, then describing how the results of that model are mapped to the survey of household spending (Statistics Canada, 2018b) in order to produce quintile level projections of indirect costs.

B.1 A Modified Version of Fellows and Dobson (2017) to Calculate Household Costs

As with the original Fellows and Dobson (2017) model, this modified version specifies 29 production sectors and 13 regions (10 provinces, Nunavut, a region representing the Yukon and Northwest Territories and a region representing Canadian production abroad).[8] Sectors in the model are represented by the subscripts i, j and k such that $i \in \mathcal{S}$ and $\{j, k\} \in \{\mathcal{S} \cup \mathcal{C}\}$ where $\mathcal{S}$ is the set of 29 production sectors and $\mathcal{C}$ is the set of final consumption sectors (Consumption, Investment and Government Spending). Regions are represented by the subscripts $\{r, q\} \in \mathcal{R}$ where $\mathcal{R}$ is the total set of 13 regions. Known parameter values are represented in lower case letters while endogenous variables are represented in upper case.

Equation (3) gives the total emissions embodied in the output from each sector/region pairing:

[8]Fellows and Dobson (2017) calculate the model for the years 2004 to 2011 with the exact number of sectors varying due to changes in the aggregation of data from Statistics Canada. However, we are only calculating the intensities for a 2011 base year as this is the most recent year possible using this model.

$$Y_{i,r} = d_{i,r} + \sum_{j \in \mathcal{S}} [B_{j,i,r}] + \sum_{q \in \mathcal{R}} [W_{i,q,r}] \tag{3}$$

where: $Y_{i,r}$ is a variable representing the total embodied emissions in sector i and region r; $B_{j,i,r}$ is a variable representing the flow of embodied emissions from sector j to sector i in region r; $W_{i,q,r}$ is a variable representing the embodied emissions flowing from sector i in region q to sector i in region r; and $d_{i,r}$ is a parameter representing the direct emissions (in tonnes of CO_2e) produced in sector i in region r.

This equation differs from the one in Fellows and Dobson (2017) in that the term representing emissions embodied in international imports is omitted. We omit imported emissions since these are assumed to be unpriced or that any price on them is not part of the Canadian framework (and therefore excluded from our assessment).

Equation (4) defines the value shares and provides an explicit value of $B_{i,j,r}$:

$$B_{i,j,r} = Y_{i,r} \cdot \left(\frac{b_{i,j,r}}{\sum_{k \in \{\mathcal{S} \cup \mathcal{C}\}} [b_{i,k,r}] + \sum_{q \in \mathcal{R}} [w_{i,r,q}] + x_{i,r}} \right) \tag{4}$$

This equation is identical to the value share equation in Fellows and Dobson (2017). The bracketed term in equation (4) represents the value share of sector j's input into sector i in region r. The numerator of this term ($b_{j,i,r}$) is the expenditure/revenue associated with of inputs flowing from sector j to sector i in region r. The denominator sums to the total gross output from sector j. Specifically $w_{j,r,q}$ is the expenditure or revenue (depending of the perspective of a consumer vs a producer) associated with inter-provincial flows of output in sector j inputs from region r to region q. $x_{j,r}$ is the revenue from international exports by sector j in region r.[9]

Also following directly from Fellows and Dobson (2017), equation (5) determines the values of the inter-regional flows (from region q to region r) of GHG emissions for each sector:

$$W_{i,q,r} = Y_{i,r} \cdot \left(\frac{w_{i,q,r}}{\sum_{k \in \{\mathcal{S} \cup \mathcal{C}\}} [b_{i,k,r}] + \sum_{q \in \mathcal{R}} [w_{i,r,q}] + x_{i,r}} \right) \tag{5}$$

The model developed in Fellows and Dobson (2017) includes an additional equation which calculates emissions embodied in international exports. However we have no reason to calculate this value in our current application, so it is omitted.

Equations (3) through (5) form a closed system of equations with a unique solution for the endogenous

[9]All parameter values in this model are based on "basic price" measures from Statistics Canada (2015b).

variables ($Y_{i,r}$, $B_{i,j,r}$ and $W_{i,q,r}$).[10]

Calibration values for the financial value parameters ($b_{i,k,r}$, $w_{i,r,q}$ and $x_{i,r}$) are identical to those used by Fellows and Dobson (2017). However, since we are interested in the embodied emissions subject to a carbon price (rather than all embodied emissions) the parameter values for $d_{i,r}$ require some modification in this application.

Specifically, we scale the Fellows and Dobson (2017) values for $d_{i,r}$ to account for the announced Output Based Pricing System (OBPS) used to address competitiveness concerns for large emitters in emissions intensive and trade exposed industries. Under this system, firm's receive an "Output Based Allocation" (OBA) which is a per unit transfer related to the level of emissions in a firm's industry, but not directly related to the firm's own emissions. The overall effect is to lower the average emissions tax rate on an industry while preserving the marginal tax rate (intended to provide an incentive not to emit and therefore to change behavior).[11] We identify the sectors and rates associated with the OBPS using the assessment done by Dobson et al. (2019).

The Provincial Symmetric Input Output Tables (Statistics Canada (2015b)) include industry data at a "Summary" level aggregation, which is roughly equivalent to a 2 or 3 digit North American Industrial Classification System (NAICS) code. However, the government's announced guidelines (and by extension the assessment in Dobson et al. (2019)) are more targeted than that, often mentioning specific sub-sectors which would be better represented at the 4 digit NAICS level. In order to account for this we calculate a weighted average OBA for each of these sectors to account for the sub-sector emissions that are covered by OBAs (at either an 80% or 90% rate) as a percentage of total sector emissions. These "effective OBA rates" are given in Table 4.

Additionally, electricity generation is treated somewhat differently than other sectors subject to the OBPS. In a standard application, the output subsidy rate is set at 80% or 90% of a sector's average emissions intensity. That is, for an 80% rate, firms receive an output subsidy that is equal to $\left\{0.8 \times \frac{\text{Total Industry} CO_2e}{\text{Total Industry revenue}} \times \text{ Firm's Revenue}\right\}$. However the currently proposed approach to electricity generation is to set an intensity standard based on a "good as best gas" equivalence. Best gas is defined as the emissions intensity per Gigawatt-hour of a modern natural gas generator which is quantified at 420 $T\left(CO_2e\right)/GWh$. Fossil generators would then be priced on any emissions produced above this threshold. Given this, the *effective* OBA rate (or, more accurately, the carbon tax charges less the out-

[10]In total, the system includes 16,211 equations and 16,211 endogenous variables. For equation (3) and $Y_{i,r}$: 29 sectors $\times$ 13 regions = 377. For equation (4) and $B_{i,j,r}$: 29 sectors^2 $\times$ 13 regions = 10,933. For equation (5) and $w_{i,q,r}$: 29 sectors $\times$ 13 regions ^{2} = 4,901

[11]For more detail and background on the OBPS see Dobson et al. (2017).

Table 4: Weighted Average Effective OBA Rates to Match Statistics Canada's Summary Level Industry Classifications

Sector	StatCan Industry Code	Effective OBA Rate (%)
Forestry and Logging	BS113	80
Fishing, Hunting and Trapping	BS114	80
Support Activities for Agriculture and Forestry	BS115	80
Crop and Animal Production	BS11A0	80
Manufacturing	BS3A0	81.34
Transportation and Warehousing	BS4B0	8.97
Coal Mining	BS210*	80
Crude Oil Extraction	BS210*	80
Natural Gas Extraction	BS210*	80
Other Mining	BS210*	85.69
Mining Support Services	BS210*	80
All Other Sectors Except Utilities		0

* The "Mining and Oil and Gas Extraction" sector (BS210) appears as a single sector in the original Statistics Canada Symmetric Provincial input output tables, however Fellows and Dobson (2017) disaggregate this into 5 sub-sectors: Coal Mining, Crude Oil Extraction, Natural Gas Extraction, Other Mining, and Mining Support Services.

put based subsidies at the sector level) is a function of the electricity generation profile in that region. As an additional complication, the industry categories in Fellows and Dobson (2017) group electricity generation into a broader sector including other utilities (such as water and sewer services). Therefore, we calculate the effective OBA rates for this sector using equation (6).

$$\Theta_{\text{Utilities},r} = \left(\frac{\text{Electricity emissions}}{\text{Utilities emissions}}\right) \times \left[1 - \frac{\sum\limits_{g=\{\text{Coal,Petroleum}\}} \Big((Intensity_g - 420) \times (\text{Share of Generation})_g\Big)}{\sum\limits_{g=\{\text{Coal,Petroleum}\}} \Big(Intensity_g \times (\text{Share of Generation})_g\Big)}\right] \tag{6}$$

where the first right hand side term $\big(\text{Electricity emissions}/\text{Utilities emissions}\big)$ is informed by data from Statistics Canada (2015a) (Physical flow account for greenhouse gas emissions); emissions intensities for petroleum and coal generation are taken from Environment Canada (2016) and the share of generation for each fuel (coal and petroleum) are taken from Natural Resources Canada (2018). The results of this calculation are in Table 5.

It is important here to note that the values in Table 5 are in no way indicative or related to the total emissions produced by the electricity generation sector in each region. For example, British Columbia has a very low level of electricity sector emissions owing to a significant portion of hydroelectric generation in the province. However, 0.1% of generation in the province uses petroleum as a fuel, and approximately 63.59% of emissions produced by petroleum fueled generators fall above the 420 $T\,(CO_2e)\,/GWh$ emissions standard. In contrast, 48.9% of Saskatchewan's electricity generation is fueled by Coal, and 40.6%

Table 5: Percentage of utilities sector emissions priced in each region

Region	Effective Rate (%)
Saskatchewan	39.70
Alberta	40.10
Nova Scotia	43.59
New Brunswick	44.97
Manitoba	48.89
Ontario	63.59
British Columbia	63.59
Newfoundland	63.59
Prince Edward Island	63.59
Quebec	63.59

of emissions produced by coal generators fall above the 420 $T\,(CO_2e)\,/GWh$ emissions standard. Ergo, the level of total emissions in the British Columbia is very low, however a larger proportion of these emissions are priced when compared to Saskatchewan.

To account for the effect of the OBPS and the electricity generation standard on *priced* emissions, we take the direct province by sector emissions from Fellows and Dobson (2017) and scale them using the OBA rates from Table 4 and the analogous parameter for the utilities from Table 5. Equation 7 relates our measure of priced emissions by sector and province to the total province and sector level emissions provided by Fellows and Dobson (2017):

$$d_{i,r} = \widehat{d_{i,r}} \cdot (1 - \Theta_{i,r}) \tag{7}$$

where $\widehat{d_{i,r}}$ is the original total sector by province emission level as applied in Fellows and Dobson (2017) and $\Theta_{i,r}$ is the effective OBA rate or analogous electricity parameter for the sector and region from Tables 4 and 5.

It follows that substituting the value for $d_{i,r}$ from equation (7) into equation (3) and solving the system of equations (3) through (5) will produce an account of the embodied priced emissions (including indirect emissions) that flow between the modeled 13 regions and 29 sectors (plus final consumption categories C,I and G).

B.1.1 A Further Modification of Fellows and Dobson (2017) to Project Revenue Raised from Households Within a Region

We have an interest in knowing what proportion of a household's indirect emissions costs will translate into revenue that stays within their home region. The ratio is not 100% due to inter-regional pass-through of costs.

Consider that consumers in a specific region will end up bearing costs associated with pricing within their region (intra-region pass-through of emissions taxes) as well as costs associated with pricing in other regions (inter-region pass-through of emissions taxes). The latter occurs when a consumer in one region directly purchases a good from another region or when a consumer in one region purchases a good that has an input (at any stage in the value chain) sourced from another region.

In the preceding section, the endogenous variable of interest ($B_{i,j,r}$) reflects the priced emissions embodied in the output of each sector i flowing to each sector j (where $j \in \mathcal{S} \cup \mathcal{C}$ reflecting that the target sectors denoted by j include final household consumption). To determine the domestic revenues, we net out inter-provincial leakage associated with end costs to households. This is a simple modification.

Starting with the already calculated values for $B_{i,j,r}$, we make the following adjustment to determine emissions that will be associated with domestic revenues associated with household consumption:[12]

$$B^{Rev}_{i,j,r} = B_{i,j,r} + \sum_{q} (W_{i,r,q} - W_{i,q,r}) \times \frac{b_{i,\text{consumption},r}}{\sum_{j \in \mathcal{C}} b_{i,j,r}} \tag{8}$$

The resulting alternative values for $B_{i,j,r}$ (reflecting embodied priced emissions net of leakage) are distinct from the values produced by the larger model described in section B.1 (reflecting total embodied priced emissions). However, both sets of values for the endogenous will map on to the survey of household spending in exactly the same way as described in section B.2 below. The distinction is that mapping the values of $B^{Rev}_{i,j,r}$ generated by the model in this section will produce a projection of the indirect or upstream domestic revenue associated with household consumption whereas mapping the values of $B_{i,j,r}$ generated by the model in the previous section will produce a projection of the indirect cost associated with household consumption (by province and quintile).

B.2 Mapping Emissions to the Survey of Household Spending

Solving for the endogenous variables in the above model (and specifically solving for the values of $B_{i,\text{consumption},r}$) provides an account of the priced emissions embodied in final household consumption across the 29 industries ($i \in \mathcal{S}$) and 13 regions (r) modeled. However, in order to determine the costs per household and the distribution of these costs across household income levels, it is necessary to map these emissions onto household spending patterns. To do this, we convert the aggregate embodied emissions

[12]Note that this calculation is not exact, given data limitations, but should be a close proxy.

values into emissions intensities. We then develop a concordance in order to map these 29 intensities onto 213 spending categories itemized in Statistics Canada's Survey of Household Spending, Statistics Canada (2018b).[13]

We calculate emissions intensities in household consumption expenditure across industries using expenditure data valued at the Purchaser Price from the same input-output tables we use to calibrate our version of the Fellows and Dobson (2017) model (specifically, Statistics Canada (2015b)).[14]

Equation 9 illustrates the calculation of emissions intensities based on purchaser price valuations:

$$\gamma_{i,r} = \frac{B_{i,\text{consumption},r}}{\widetilde{b}_{i,\text{consumption},r}} \tag{9}$$

where the values of $gamma_{i,r}$ are emissions intensities of the form: Tonnes of CO_2e per dollar of household purchase expenditures by sector i and region r and the values of $\widetilde{b}_{i,\text{consumption},r}$ are total dollars of household purchase expenditures by sector i and region r.[15]

These intensities are then mapped to the expenditure categories in Statistics Canada's Survey of Household Spending, (Statistics Canada (2018b)). We define these categories using the subscript $n \in \mathcal{N}$ and $m \in \{\mathcal{N} \cup \mathcal{A}\}$ where $\mathcal{N}$ is the set of expenditure categories at the lowest level of aggregation and $\mathcal{A}$ represents expenditure categories that are themselves aggregates of the categories in set $\mathcal{N}$.

Statistics Canada uses different data collection methodologies in Statistics Canada (2018b) as compared to Statistics Canada (2015b) so there is no direct concordance to ensure consistency. Because of this, we are forced to develop our own concordance. We do this by comparing the category descriptions of the elements of $\mathcal{N}$ and $\mathcal{S}$ and defining a best match. The mapping only goes in one direction, such that each element of $\mathcal{N}$ is matched to exactly one element of $\mathcal{S}$ but an element from $\mathcal{S}$ could be matched to zero or more elements of $\mathcal{N}$.

As indicated in section B.1 we calculate intensities based on 2011, as this is the most recent year to which the Fellows and Dobson (2017) model has been applied. Because these intensities are based on a nominal value base, in order to apply them to different years they must be adjusted for inflation. To

[13] Statistics Canada (2018b) itemizes 318 categories of household spending, however; 84 of these are aggregates of more detailed spending. We explain our approach to aggregation below. Further, 21 of the categories are associated with expenditures that have no associated emissions (such as "Forfeit of deposits, fines, and money lost or stolen") and therefore do not require mapping.

[14] In calibrating the model we made use of valuations based on "basic price", rather than valuations based on "purchaser price." The basic price valuation nets out subsidies, taxes and various margins on exchange. It represents the closest measure of the economic value of a product so it is used in defining the parameter values of the model outlined in section B.1 above. The purchase price valuation is more analogous to the measures of spending represented in the survey of household spending as it reflects a measure of expenditure on industry output, rather than the value of that output.

[15] Note that $\tilde{b}_{i,\text{consumption},r}$ is directly analogous to the values of $b_{i,j,r}$ (indicating a financial revenue/expenditure flow) wherein $j \equiv$ consumption and with the $\tilde{}$ indicating the use of a purchaser price valuation rather than the basic price valuation.

maintain the highest level of accuracy in our projections as possible, we deflate these intensities using individual price indices for each element of $\mathcal{N}$.

With the mapping in place we redefine $\gamma_{i,r}$ over the set $\mathcal{N}$ instead of $\mathcal{S}$ and add a time dimension $t \in \{2010, 2011, 2012, 2013, 2014, 2015, 2016\}$ as well. Formally:

$$\left\{\gamma_{n,r,t} = \frac{\gamma_{i,r}}{p_{n,t}} \ \mid n \mapsto i\right\} \ \forall n \in \mathcal{N}$$

where the values of $p_{n,t}$ are price indices with a base year of 2011 for each spending category n and time period t. The values for $p_{n,t}$ are calculated using data from Statistics Canada (2018a).[16]

We then calculate the emissions embodied in household consumption by spending category $\mathcal{N}$ and income quintiles for each region. Income quintiles are denoted by the subscript $h \in \{1, 2, 3, 4, 5\}$:

$$\Omega_{n,h,r,t} = E_{n,h,r,t} \cdot \gamma_{n,r,t} \ \ \forall n \in \mathcal{N} \tag{10}$$

where $E_{n,h,r,t}$ is a parameter representing the level of household expenditure by spending category, income quintile, region and year (as taken from Statistics Canada (2018b)) and $\Omega_{n,h,r,t}$ is our calculated value for embodied priced emissions in household expenditure by spending category, quintile, region and year.

Unfortunately, statistics Canada suppresses certain values in the survey of household expenditure (Statistics Canada (2018b)) for data quality reasons. The values ($E_{n,h,r,t}$) are therefore missing for some elements of set $\mathcal{N}$, however they are accounted for in the more aggregated spending categories in set $\mathcal{A}$. To address this issue, we calculate weighted average emissions intensities using data for the observable sub-sectors for each element of the set $\mathcal{A}$ and apply them to that element. Since some elements of the set $\mathcal{A}$ are aggregates which encompass other elements that are themselves also aggregates (and therefore in set $\mathcal{A}$) we do this calculation in steps, working from the lowest level of aggregation to the highest. The calculation in each step takes the form:

$$\Omega_{m,h,r,t} = E_{m,h,r,t} \cdot \frac{\sum_{\{n|n \mapsto m\}} [\gamma_{n,r,t} \cdot E_{n,h,r,t}]}{\sum_{\{n|n \mapsto m\}} [E_{n,h,r,t}]} \tag{11}$$

where the summations on the top and bottom of the fraction indicate a sum over all of the values of n such that n maps to (or is a sub-category of) the element $m \in \mathcal{A}$. Exact notation becomes needlessly complex as we move to subsequent steps. However it should suffice to describe the process as follows;

[16] Specifically, we convert the monthly CPI numbers from Statistics Canada (2018a) into simple annual average and then re-base the index to a 2011 base year to match our 2011 intensity calculations.

in the first step (which directly corresponds to equation 11) the calculation is performed for all elements $m \in \mathcal{A}$ wherein the subcategories of m (specifically, all n such that $n \mapsto m$) all belong to set $\mathcal{N}$. In subsequent rounds, we add any element for which a value of $\Omega_{m,h,r,t}$ has been calculated to the set $\mathcal{N}$ and remove it from the set $\mathcal{A}$. We then calculate a value $\gamma_{n,r,t} = \frac{\Omega_{m,h,r,t}}{E_{m,h,r,t}}$ for that element and recalculate equation (11) using the same process as before. This works because, as we move elements from set $\mathcal{S}$ to set $\mathcal{A}$ a new portion of the elements $m \in \mathcal{A}$ satisfy the requirement that the subcategories of m all belong to set $\mathcal{N}$.

The entire set of spending categories ($\mathcal{N} \cup \mathcal{A}$) represent six levels of aggregation. As such, we perform the above described step 6 times in order to reach the most aggregated spending category ("Total expenditure").

To calculate the indirect costs associated with each spending category, quintile, region and year, we multiply an assumed carbon price ($ per tonne of CO_2e) in each year denoted τ_t by the measure of embodied priced emissions in household spending $\Omega_{m,h,r,t}$:

$$C_{m,h,r,t} = \tau_t \cdot \Omega_{m,h,r,t} \tag{12}$$

where $C_{m,h,r,t}$ is the indirect cost of emissions pricing for each spending category, quintile, region and year. The total cost to each household is then found within this set. Specifically a specific value for $n \equiv$ Total expenditure:

$$C_{\text{Total expenditure},h,r,t} = \tau_t \cdot \Omega_{\text{Total expenditure},h,r,t} \tag{13}$$

If, instead of using the values for $B_{i,\text{consumption},r}$ from the model described in section B.1, we instead use the values from the restricted model described in section B.1.1, the result is that the calculated values for $C_{\text{Total expenditure},h,r,t}$ would describe the indirect or upstream domestic revenue associated with household consumption (rather than the household costs).

C Appendix: Household Energy Use Characteristics

Here we present basic household built environment characteristics, by province, that we use to construct our energy use and emissions estimates.

TO BE COMPLETED.

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