Learning from 19 Carbon Taxes: What Does the Evidence Show?

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ABSTRACT

Carbon taxes have been enacted in 16 countries, two Canadian provinces, and even one city. Evaluations of some of these carbon taxes have been conducted. In other cases available data can be examined to shed light on impacts, although separating out the impact of carbon taxes and that of other policies is difficult.

This paper briefly summarizes carbon taxes in these various jurisdictions and then explores available evidence on their impacts, with a focus on energy use and carbon emissions. It emphasizes jurisdictions with the most-rigorous studies.

Overall the available evidence indicates that carbon taxes have contributed to reductions in energy use and carbon emissions. Reductions have generally been moderate; tax levels have also been moderate. Reductions in the industrial sector have been more substantial when the tax has applied to industrial firms, but significantly less so when some or all of a firm's tax obligations have been waived. More study is needed, particularly on long-term impacts and impacts in the residential and commercial sectors, where available studies are particularly limited. Experience to date indicates that at the carbon-tax levels that have been politically feasible so far, carbon taxes can be useful but will need to be complemented with other policies to achieve targeted levels of carbon emissions.

Introduction

Carbon taxes have been enacted in 16 countries, two Canadian provinces (British Columbia and Quebec), and one city (Boulder, Colorado). To keep the scope of this paper to manageable levels, we include only carbon taxes in this paper and do not include other policies that indirectly impose prices on carbon emissions, such as cap and trade programs. Evaluations of some of these carbon taxes have been conducted. In other cases available data can be examined to shed light on impacts. In both cases separating out the impact of carbon taxes from that of other policies is difficult.

This paper briefly summarizes carbon taxes in these various jurisdictions and then explores available evidence on the impact of these taxes, with a focus on energy use and carbon emissions. We begin with an overarching analysis of energy use and carbon emissions trends in each country, comparing the period before and after the carbon tax took effect and comparing each country to a basket of similar countries. Next we review available evaluation results on carbon taxes in many of the countries, emphasizing jurisdictions with the most-rigorous studies. We conclude with a discussion of lessons learned and outstanding questions.

Carbon Taxes around the World

Previous authors have summarized carbon taxes now in place. Marron et al. (2015) have a comprehensive recent summary. As of this writing, Wikipedia (2016) also contains a good summary. Table 1 summarizes the carbon taxes that have been enacted.

Table 1. Carbon taxes around the world

Country/ jurisdiction	Year adopted	Tax rate (US$/t$CO_2$e)*	Sectors covered	Coverage rate (% of GHG)
Australia	2012 (repealed 2014)	20	Emissions from electricity generation, stationary energy producers, mining, business transport, and waste and industrial processes	NA
Boulder, Colorado	2007	12–13	Electricity purchases except utility-provided wind power	NA
British Columbia	2008	25	Purchase or use of fuels	70
Chile	2014	5	Emissions from the power sector	55
Costa Rica	1997	3.5% on hydrocarbon fossil fuels	Fossil fuels	85
Denmark	1992	31	Consumption of fossil fuels, with exemptions	45
Finland	1990	40	Heat, electricity, transportation, and heating fuels	15
France	2014	8	Fossil fuel products, based on CO_2 content	35
Iceland	2010	10	Imports of liquid fossil fuels	50
Ireland	2010	23	Fossil fuels not covered by EU ETS	40
Japan	2012	2	Fossil fuels by CO_2 content	70
Mexico	2014	1–4	Fossil fuel sales and imports	40
Netherlands	1990	74	Natural gas, electricity, gasoline, diesel, and several specialized fuels	NA
Norway	1991	4–69	Mineral oil, gasoline, and natural gas	50
Quebec	2007	3	Gasoline, diesel fuel, propane, and coal	NA
South Africa	2016	10	Emissions from fuel combustion and nonenergy industrial processes	80
Sweden	1991	168	Fossil fuels for heating and motor fuels	25
Switzerland	2008	68	Fossil fuels not used for energy or covered by EU ETS	30
United Kingdom	2001	16	Fossil fuels used to generate electricity	25

Source: Marron et al. 2015. Boulder, Netherlands, and Quebec from Sumner et al. 2009. Australia from Carbon Tax Center 2015. Netherlands tax rate calculated from data in IEEP 2013 and EIA 2015.
Notes: GHG = greenhouse gases. EU ETS = European Union Emissions Trading System. tCO_2e = metric ton (tonne) CO_2 equivalent. NA = not available. There is also a 4.5-cents-per-tonne tax in the San Francisco Bay Area.
* Amounts have been converted to US dollars using early-2015 exchange rates. Tax rates are for 2013 or 2014, except for Chile (2018), Netherlands (2010), Quebec (2007), and South Africa (2016). As best we can tell the Quebec tax has not changed in recent years.

As table 1 shows, current carbon taxes span an enormous range, from a mere $1 to as much as $168 per metric ton (tonne) of CO_2 equivalent. The median tax in table 1 is $18 per tonne. There is also a wide range in tax coverage, with the carbon taxes shown applying to 15–80% of greenhouse gas emissions, with a median of 45%. To put the $18-per-tonne figure in perspective, we calculated what an $18-per-tonne carbon tax would mean for natural gas, gasoline, and coal in the United States and compared these price impacts to the average 2015 price for these fuels in the United States. For these calculations we used estimates of average energy prices, energy content per unit of fuel, and carbon dioxide emissions per British thermal unit (Btu) for each of these fuels.[1] We found that an $18-per-tonne CO_2 fee would increase average 2015 energy prices by 14% for natural gas, 6% for gasoline, and 75% for coal purchased by electric generating stations. Only the impact on coal prices can be considered large.

Analysis of Energy Use and Carbon Emissions

We begin our review of climate tax impacts by examining basic data on energy and carbon intensity in eight countries with significant carbon taxes. We look at countries with carbon taxes of US$10 per tonne or more for which at least two years of post–carbon tax data are available. We focus on countries since we can use the same data source for all—the international energy statistics compiled by the Energy Information Administration (EIA 2016). Our analysis looks at all energy use and carbon emissions for a country. This is a simple indicative analysis, and we did not look at either the impact of the carbon tax level (dollars per tonne) or coverage (percentage of greenhouse gas emissions covered).

We prepared two comparisons for each country. First, we looked just at each country, comparing annual percentage change in energy and carbon intensity for the five years before the carbon tax was enacted to the five years after enactment. (For Switzerland, only a two-year comparison was possible.) Energy intensity is energy use divided by gross domestic product (GDP). Carbon intensity is carbon emissions divided by GDP. Second, we compared annual rate of change in energy and carbon intensity for each country from enactment of each carbon tax through 2011, to the rate of change in the same period for all Organization for Economic Cooperation and Development (OECD) countries. OECD is a group of 34 of the world's most developed countries. Our analysis goes through 2011 only since that is the last year with data reported by EIA as of the date of this writing. We report our results in tables 2 (for energy intensity) and 3 (for carbon intensity).

In the majority of cases (63–75%, depending on the metric) rates of change are lower in the after-tax period than in either the pretax period in the same country or the after-tax period in all OECD countries. These are crude comparisons, as many factors could have contributed to these trends besides carbon taxes. We report them here as only a rough and preliminary indication. On average across the countries, energy intensity declined by 0.5% and 0.8% more per year in the after-tax period relative to our two control metrics, while carbon intensity declined by 0.1% and 0.7% more per year. Since the median carbon tax applies to only 45% of emissions (see table 1), we would expect the 0.1-0.8% per year relative reductions to roughly double if a carbon tax were to apply to all emissions.

[1] Energy prices come from EIA's *Monthly Energy Review* for natural gas and gasoline (www.eia.gov/totalenergy/data/monthly/) and from www.eia.gov/forecasts/steo/report/prices.cfm for coal; Btu content of fuels comes from www.eia.gov/Energyexplained/?page=about_energy_units, and emissions per Btu comes from www.eia.gov/tools/faqs/faq.cfm?id=73&t=11.

Table 2. Energy intensity trends pre– and post–carbon tax

	Year of	Annualized Change in Energy Intensity				Differences	
Country	C tax	5 yrs before	5 yrs after	Country after	OECD after	B - A	C - D
		[A]	[B]	[C]	[D]		
Costa Rica	1997	1.0%	1.4%	-0.8%	-1.4%	0.4%	0.6%
Denmark	1992	-0.5%	-1.5%	-1.9%	-1.2%	-1.0%	-0.7%
Finland	1990	-1.4%	-1.1%	-1.5%	-1.1%	0.3%	-0.4%
Netherlands	1990	-0.5%	-1.2%	-1.2%	-1.2%	-0.7%	0.0%
Norway	1991	0.2%	-4.0%	-1.9%	-1.2%	-4.2%	-0.7%
Sweden	1991	-2.0%	-1.4%	-2.7%	-1.2%	0.6%	-1.5%
Switzerland	2008	-2.7%	-4.1%	-2.0%	-1.2%	-1.4%	-0.8%
United Kingdom	2001	-2.9%	-3.6%	-1.4%	-1.2%	-0.7%	-0.2%
Average						-0.8%	-0.5%
% with expected impacts (shaded cells)						63%	75%

Notes:

- *5 yrs before* and *5 yrs after* are the periods before and after the carbon tax took effect. The year the tax took effect is not included.
- *Country after* covers the period between the year after the carbon tax took effect and 2011.
- *OECD after* is for all OECD countries for the same period covered in the column to the left. (The years covered by this column vary depending on the year the carbon tax took effect.)
- The comparison for Switzerland covers only two years before and after the carbon tax; later data are not available.

Table 3. Carbon intensity trends pre– and post–carbon tax

	Year of	Annualized Change in Energy Intensity				Differences	
Country	C tax	5 yrs before	5 yrs after	Country after	OECD after	B - A	C - D
		[A]	[B]	[C]	[D]		
Costa Rica	1997	3.7%	-0.5%	-0.8%	-1.4%	-4.2%	0.6%
Denmark	1992	-1.4%	-3.0%	-3.3%	-1.5%	-1.6%	-1.8%
Finland	1990	-0.1%	-0.6%	-2.1%	-1.4%	-0.5%	-0.7%
Netherlands	1990	-1.0%	-1.6%	-1.6%	-1.4%	-0.6%	-0.2%
Norway	1991	-1.3%	-1.4%	-1.4%	-1.5%	-0.1%	0.1%
Sweden	1991	-4.0%	0.1%	-2.9%	-1.5%	4.1%	-1.4%
Switzerland	2008	-5.7%	-4.4%	-2.1%	-1.5%	1.3%	-0.6%
United Kingdom	2001	-3.5%	-2.6%	-3.0%	-1.6%	0.9%	-1.4%
Average						-0.1%	-0.7%
% with expected impacts (shaded cells)						63%	75%

- Notes for table 2 also apply to this table.
- Sweden stands out in the B - A column. As we discuss in the text, the Swedish carbon tax was reduced in 1993, which caused emissions to climb.

Significant Evaluation Studies

Next, we examined available evaluation studies, finding studies on British Columbia and eight countries (Australia, Denmark, Norway, Sweden, Finland, the Netherlands, Ireland, and the United Kingdom). We discuss results by jurisdiction in the sections below.

British Columbia

British Columbia (BC) adopted a carbon tax on fuel use in 2008. Much has been written about the British Columbia tax, most recently by Murray and Rivers (2015) and Komanoff and Gordon (2015). In BC most electricity comes from zero-carbon hydroelectric power, so the carbon tax has little effect on electricity use in the province. Many of the studies have focused on gasoline and diesel use for transportation, although some studies looked at the overall economy and one study looked at natural gas use in buildings.

Changes in use of vehicle fuels can be observed in per capita consumption in BC relative to the rest of Canada. While fuel use declined in both BC and Canada in 2009 (during the Great Recession), the two have diverged since then, as figure 1 shows.

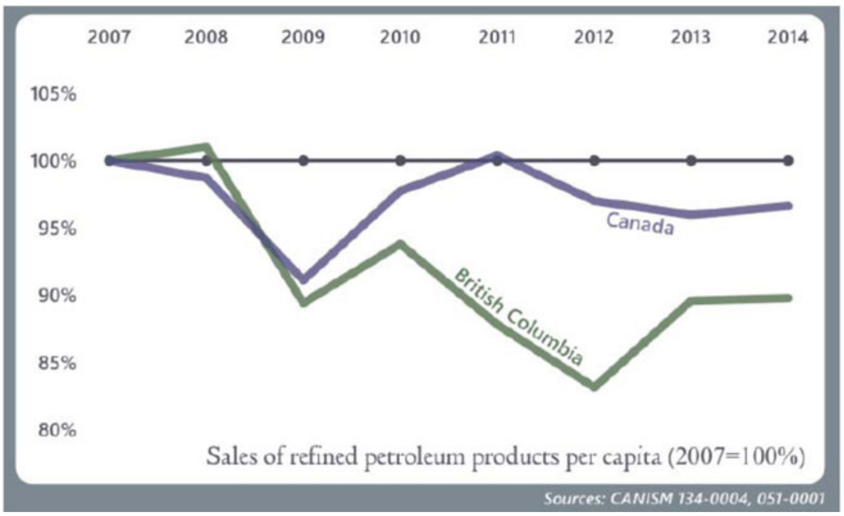

Figure 1. Comparison of petroleum consumption in British Columbia and Canada, 2007–14.
Source: Durning and Bauman 2014.

For petroleum fuels, probably the most comprehensive study was by Rivers and Schaufele (2012), who conducted an econometric analysis comparing BC gasoline use with that of other provinces and controlled for other covariates that could affect gasoline sales, such as income, prices, the business cycle, and public-transit investments.[2] Their coefficients suggested that the BC carbon tax caused a reduction of 11–17% in gasoline sales. They noted that this effect was much larger than would be expected if consumers responded to the carbon tax in the same way that they responded to other changes in gasoline price. Murray and Rivers (2015) summarized this and other studies on the BC carbon tax, as table 4 shows. In the case of transportation fuels, in addition to the 11–17% reduction found by Rivers and Schaufele, they cited studies finding reductions of 18.8% and 7%.

[2] Listing and analyzing the details of the econometric models used in this study and others would be a useful endeavor but is beyond the scope of this short paper.

Table 4. Results of evaluations of British Columbia's carbon tax

Source	Method	Results
British Columbia (2008)	Numerical simulation model with technological detail	5% reduction in GHG emissions
Beck et al. (2015)	Computable general equilibrium model	8.5% reduction in GHG gas emissions
Elgie and McClay (2013)	Difference-in-difference with no additional controls	18.8% reduction in per capita sales of petroleum fuels subject to the tax
Elgie and McClay (2013)	Difference-in-difference with no additional controls	9% reduction in per capita GHG emissions (data to 2011 only)
Rivers and Schaufele (2012)	Difference-in-difference with controls	11–17% reduction in per capita gasoline sales
Gulati and Gholami (2015)	Difference-in-difference with controls	15% reduction in residential natural gas demand; 67% reduction in commercial natural gas demand
Bernard, Guenther, and Kichian (2014)	Time series analysis	7% reduction in per capita gasoline sales

Source: Murray and Rivers 2015. Full citations are in that paper. The first study is a pretax projection. Figures given for Gulati and Gholami were derived by Murray and Rivers.

A more recent study, by Antweiler and Gulati (2016), used multistage regression models to compare BC to other Canadian provinces on gasoline demand and vehicle purchase decisions, controlling for a variety of factors including cross-border trips to the United States, where gasoline taxes are lower and many goods are cheaper. Results are still preliminary, but their preferred model "suggests that without BC's carbon tax, fuel demand per capita would be 7% higher, and the average vehicle's fuel efficiency would be 4% lower." Their savings estimates are lower than other estimates due to the effect of the tax on cross-border trips during a period when currency exchange rates were skewed.

For buildings, Gulati and Gholami (2015) analyzed residential and commercial natural gas sales using a similar approach to that of Rivers and Schaufele (2012). They found that the carbon tax caused declines in both residential and commercial consumption. The commercial decline is statistically significant; the residential decline is not. Murray and Rivers (2015) applied the carbon tax coefficients Gulati and Gholami developed, noting that the carbon tax appears to have reduced commercial natural gas consumption by a much larger amount than would be expected on the basis of the normal response to changing commercial natural gas prices.

Table 4 also includes the results of several studies looking at the effects of the carbon tax on provincial greenhouse gas emissions in all sectors. These studies found greenhouse gas reductions due to the carbon tax of 5%, 8.5%, and 9%. More recently, Komanoff and Gordon (2015) compared the pre- and post-tax periods in BC and the rest of Canada, finding that BC emissions (excluding the electric sector) declined 6.1% while emissions in the rest of Canada rose 3.5%, a difference of 9.6%. For emissions per capita and emissions per dollar of GDP, both BC and Canada declined, with the difference being 9.2% for emissions per capita and 12.4% for emissions per dollar of GDP.

Murray and Rivers (2015) also summarized a variety of studies looking at the impact of the BC carbon tax on economic activity. While a full discussion of economic impacts is beyond the scope of our paper, it is useful to note that Murray and Rivers concluded that: "In summary, empirical evidence on the effects of the BC carbon tax on economic performance—though based on a somewhat limited number of studies—suggests little net impact in either direction. There is some evidence of negative effects in emissions-intensive sectors, such as cement, but the positive impacts in other sectors appear to compensate for those effects."

Overall most observers consider the BC carbon tax a success, and there are now proposals to increase the tax.

Australia

Australia imposed a carbon tax in July 2012, covering fuels used to generate electricity and several other sectors, though not motor fuels for passenger transportation. The tax was rescinded in July 2014 when a new national government repealed it. Thus Australia provides a potentially unique test case for looking at changes when the tax began and again when it ended.

The changes are perhaps best illustrated by a set of two graphs from The Australia Institute (2015). The first (figure 2) displays CO_2 emissions from the electricity and petroleum sectors over the 2006–14 period, showing a sharp drop in electric-sector emissions beginning when the tax began, with emissions rebounding as soon as the tax ended. Petroleum emissions were not affected as petroleum was untaxed.

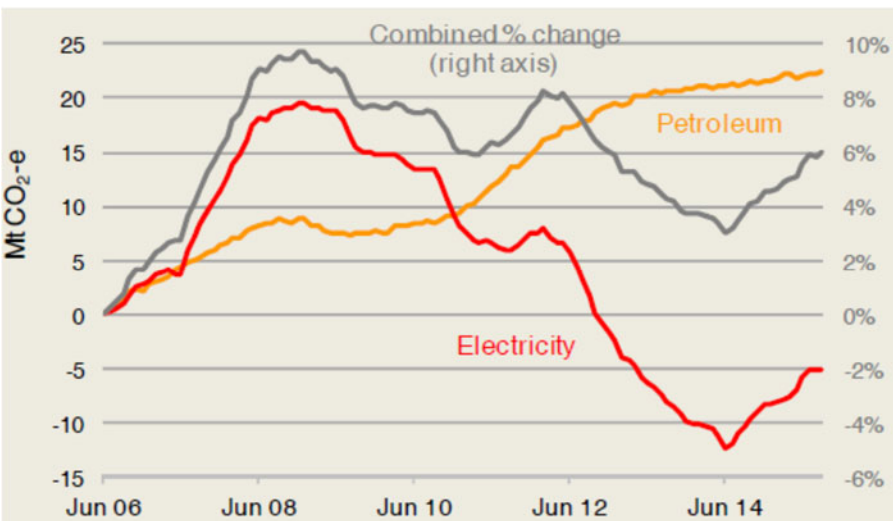

Figure 2. Change in CO_2 emissions in Australia from the electricity and petroleum sectors and both sectors together, 2006–14. The left-hand scale is in tonnes, the right-hand scale in percentages, both relative to June 2006 emissions (pretax). *Source*: The Australia Institute 2015.

The second graph (figure 3) shows how the electricity generation mix changed during this period, with brown and black coal use declining during the carbon tax period and then rebounding after. Renewable energy and natural gas use grew gradually during the 2008–14 period, but since the tax ended hydropower and natural gas use have dropped. One observer reported that utilities, knowing the carbon tax was about to end, drew down their supplies of stored hydroelectricity in the months before the tax ended, resulting in a drop in hydropower use in the months after the tax ended (Saddler 2015).

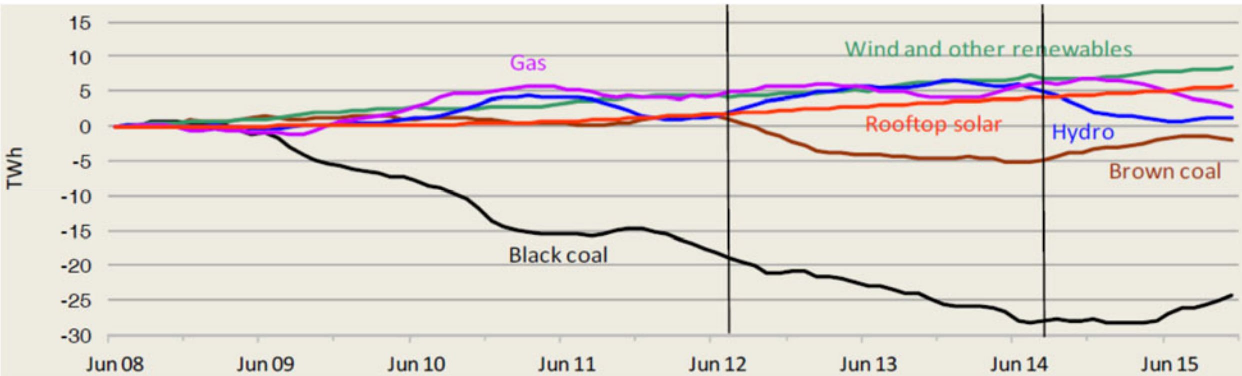

Figure 3. Changes in electricity generation by fuel type in Australia, 2008–15. *Source*: The Australia Institute 2015.

Additional information is provided in a paper by O'Gorman and Jotzo (2014), who looked at the impact of the carbon tax on Australia's electricity demand and emissions. They noted that over the two years the carbon tax was in effect, electricity use declined by 3.8% in the national electricity market (the Australian grid), overall carbon emissions declined by 8.2%, and the emissions intensity of the electricity supply declined by 4.6%. They used a variety of analyses to estimate that the carbon price caused 28–50% of the decline in electricity usage, with the rest of the decline attributable to other factors, particularly increases in electricity prices due to investments in the grid that were unrelated to the carbon tax.

Nordic Countries

Carbon taxes of some sort have been used in most of the Nordic countries since the early 1990s including in Denmark, Finland, Norway, and Sweden. As table 1 shows, the Nordic taxes tend to be in the upper half of the range of carbon taxes. All cover many types of fossil fuels, although tax reductions for industry are common. Only Finland covers electricity. The taxes in the Nordic countries have gone through many changes over the years, often beginning as energy taxes and introducing a climate angle in more recent years. A variety of studies have looked at the impacts of these taxes. Andersen et al. (2000) summarized many of these studies in English. In the paragraphs below we discuss several studies, which look at post-tax impacts and not merely predictions.

Norway. Larsen and Nesbakken (1997) used models of different sectors of the Norwegian economy and actual data from 1987–93 to back-cast the impact of Norway's CO_2 tax. As summarized by Andersen et al.: "The tax's effect on different types of industries varied greatly.… On aggregate, the effect of the tax on oil for heating in industry was a reduction in Norwegian emissions of approx. 0.5% in 1991. The estimated effect of the tax on total household heating in the period 1987-93 was a fall of between 0.1 and 0.5%; this low figure is mainly due to the fact that energy consumption in the sector was not all that high anyway. Finally, the analysis showed that there would have been 2-3% more private vehicular traffic from 1991-93 if a tax had not been introduced—on the other hand public transport rose by 0.5%. The total effect of the CO_2 tax on the analyzed sectors was 3-4% lower emissions 1991-93."

In addition a pair of studies by the firm ECON (1994 and 1997) interviewed firms in the oil industry on the impact of the carbon tax on specific investment decisions. Results of the two studies were similar. For the 1997 study, as summarized by Andersen et al.: "The total effect of the measures has been that the CO_2 emissions from the continental shelf are 8% less than they would otherwise have been; of this 3% can be directly ascribed to measures that have become financially viable because of the CO_2 tax. The tax has also drawn attention to measures that would have been financially viable with or without the tax."

More recently Bruvoll and Larsen (2002) decomposed emissions changes over the 1990–99 period using an applied general equilibrium simulation to look into the specific effect of carbon taxes. They found: "Despite considerable taxes and price increases for some fuel-types, the carbon tax effect has been modest. While the partial effect from lower energy intensity and energy mix changes was a reduction in CO_2 emissions of 14 percent, the carbon taxes contributed to only 2 percent reduction. This relatively small effect relates to extensive tax exemptions and relatively inelastic demand in the sectors in which the tax is actually implemented."

In sum, all of the evaluations of the Norwegian tax find that it contributed to modest emissions reductions.

Sweden. NUTEK (1994) conducted an analysis somewhat similar to the Bruvoll and Larsen analysis of Norway, comparing post-1994 energy use and emissions with those from the pre-carbon regime in 1990. Based on this analysis NUTEK concluded that the tax changes in 1991–94 reduced emissions by 3–5% in 1994 compared to a situation in which the 1990 system was continued.

The Swedish Environmental Protection Agency performed a similar analysis (1995) and found a 10% emissions reduction attributable to the tax when the transport sector was excluded, with emissions falling in all sectors other than transport. The agency estimated that 60% of Swedish emissions reductions during the 1990–94 period were due to the CO_2 tax. It found that district heating systems were very sensitive to the tax, while the household sector and industry were less sensitive. (In the case of industry this finding particularly applied after the industrial tax rate was cut, at the beginning of 1993.)

NUTEK (1995) looked further into the effect of the 1993 changes in the industrial tax, finding that industrial production and energy use increased in 1993 due to the combination of the lower tax and oil price declines in world markets. NUTEK estimated that about 16% of the increased industrial oil use in 1993 was attributable to the reduced carbon tax. In addition the study found that the district heating sector increased use of biofuels by about 80% in 1994 relative to 1990. NUTEK also concluded that the taxes helped make energy-saving initiatives viable in the household sector and hastened technical progress on energy-conserving products. Furthermore it found that the increased gasoline taxes led to lower gasoline consumption, but other unstated factors had the opposite effect.

Bohlin and Rosenqvist (1998) looked at the impacts of the Swedish taxes over the 1990–95 period. They found that "[t]he effects of the tax vary across sectors. Biofuel use in the district heating sector increased from 36.7 petajoules [PJ] to 73.4 PJ, replacing primarily coal, thus leading to great carbon dioxide savings. Dynamic effects of the tax include development of new industry for refined wood fuels and extraction machinery. Transports have not been affected. Industry pays lower taxes on fossil fuels with the differentiated tax than it did before the tax was introduced, leading to increased fossil fuel use." Overall they estimated that carbon abatement during the period they analyzed ranged from 0.5 million to 1.5 million tons of CO_2 on a yearly basis. This is about 0.8–2.5% of average Swedish CO_2 emissions during this period.

In sum, while Sweden has a high carbon tax (see table 1), it has been inconsistently applied and results in only modest overall emissions reductions. One notable impact is increased use of biomass for district heating.

Denmark. Bjørner and Jensen (2002) conducted an econometric analysis on time series data on more than 3,000 Danish industrial companies. They concluded that in 1997 the companies' energy use would have been 10% higher if they had not paid any emissions tax. In Denmark the tax is moderately reduced for companies that enter into voluntary energy-saving agreements with the government. Bjørner and Jensen found that these agreements reduced energy use by 9% for participating companies. They also found that the tax reduction associated with these agreements increased energy use by 1–5%, but that on net, the savings from the agreements are greater than the lost savings due to the tax reductions.

Enevoldsen has conducted a series of analyses of the impact of the carbon tax on Danish industrial CO_2 emissions. In his most recent study (2005), using a two-step time-series analysis, he estimated that over the 1992–2000 period Danish CO_2 and sulfur dioxide (SO_2) taxes together (industry preferred a combined tax to a higher CO_2-only tax) reduced industrial CO_2 emissions by 9–11%. His analysis also separated out the impacts of two other policies—subsidies for energy saving (industrial CO_2 reduction of 1–2%) and subsidies for combined heat and power (CHP) systems (reduction of 2.5–3.5%). The three policies combined reduced Danish industrial emissions over this period by 12.5–16.5%.

In sum, the carbon tax plus associated voluntary agreements appear to contribute to significant emissions reductions in Denmark; other policies contribute additional reductions.

Finally, Lin and Li (2011) conducted a difference-in-difference analysis of per capita CO_2 emissions in the four primary Nordic countries as well as the Netherlands, relative to emissions in 13 European countries without carbon taxes. They found that per capita emissions declined in Finland, Denmark, Sweden, and the Netherlands relative to the other European countries, while emissions per capita increased modestly in Norway. The difference was statistically significant only for Finland. They found that "the mitigation effects of carbon tax are weakened due to the tax exemption policies on certain energy intensive industries in these countries."

The Netherlands

The Netherlands has had a combined energy and carbon tax since about 1990. In the early years it was fairly moderate, averaging $20 per tonne in 1996 (Sumner et al. 2009), but it is indexed for inflation, and in recent years Dutch environmental taxes have risen to be among the highest in Europe (IEEP 2013).

We found two impact evaluations on the Dutch energy and carbon tax, one each on the industrial and housing sectors. For the industrial sector Enevoldsen (2005), in the same study discussed above for Denmark, also examined the impact of various policies in the Netherlands. In the Netherlands the primary industrial policy is voluntary agreements between the government and industrial sectors. The government waives the energy and carbon tax for large firms that enter into such agreements. Many firms have done this. In his analysis Enevoldsen estimated that over the 1992–2000 period, the voluntary agreements reduced Dutch industrial CO_2 emissions by 1.8–3.4%, the carbon and energy taxes together saved 1–2%, energy-saving subsidies saved 0.5–1%, and CHP subsidies saved roughly 0.5–1%. Together these policies reduced industrial emissions by 4–7.5%. Because the Dutch tax is reduced for industry, the effective tax levied on industry is substantially lower than in Denmark. Enevoldsen found that the Danish tax had a larger impact on industrial emissions than the combination of the Dutch tax and voluntary agreements.

For the housing sector Berkhout et al. (2004) conducted an econometric analysis on the effect of the energy tax. They found that the tax reduced average household electricity and natural gas use by 8% and 4.4%, respectively. They also found that household demand for electricity was more elastic than demand for natural gas and suggested that non-taxation policies were needed to reduce household natural gas use.

Ireland

Ireland began implementing several emissions-related taxes in 2010. The European Union (EU), of which Ireland is a member, has an emissions-trading scheme for the power sector and heavy industry. The Irish taxes were targeted at other sectors, specifically transport and heat in buildings. The carbon tax is levied on fossil fuels when they enter the country and are passed on to consumers at the point of purchase. In addition there is an automobile sales tax, which ranges from 14–36% of a car's market price depending on its emissions. In 2011 Ireland's CO_2 emissions declined 6.7%, even as the economy grew slightly, and in that year 90% of new-car sales were in the two lowest-emission bins (Rosenthal 2012). In 2010 and 2011, the first two years of the tax, transport fuel use was 8% and 9% lower, respectively, relative to 2009 levels (Convery 2012). No detailed analyses are available that attempt to identify the specific impact of these taxes relative to other possible explanatory factors.

United Kingdom

The United Kingdom's Climate Change Levy (CCL) began in 2001 and applies to energy used by industries, businesses, and the public sector. The CCL is linked to climate change agreements (CCAs), under which energy-intensive businesses are eligible to receive a 65% discount on the CCL (increased to 90% in 2013) if they meet energy efficiency or carbon-reduction targets. The CCAs have been controversial, with some arguing that the agreements helped win management support for energy-saving investments and others arguing that the agreement targets were too weak and captured many actions that would have happened anyway (IEEP 2013).

We found two studies on the impacts of these policies. First, a 2005 study compared actual energy use in 2002 with what use would have been without the CCL, as estimated with a detailed model of the UK economy. This study looked at the entire UK economy and found that in 2002 the CCL reduced carbon emissions by 3.1 million tonnes (National Audit Office 2007), about 2% of the United Kingdom's emissions that year (EIA 2015).

In contrast, an econometric analysis by Martin and Wagner (2009) looked at detailed data on UK industrial firms only and found that "CCA participation is associated with a 15% increase in the growth in energy expenditures and a more than 20% increase in the growth in energy intensity." These trends were statistically significant. In other words the CCAs did not save energy in the industrial sector but were instead vehicles for avoiding the CCL. They also found "no evidence of an impact of the CCL on output, employment and total factor productivity" and "evidence that the CCL induces more innovative activity in firms than the CCA." (The latter conclusion resulted from an analysis of patents.) They concluded that "our results strongly suggest that further cuts in energy use of substantial magnitude could have been achieved without jeopardizing economic performance if the CCL had been implemented at full rate for all businesses."

Discussion and Next Steps

Our analysis of energy use and carbon emissions in countries with carbon taxes in place for at least two years (shown in tables 2 and 3) finds that countries reduced their energy-use and carbon-emissions intensities by an average of 0.1–0.8% per year, with the reduction varying by the metric and control used. This is a rough analysis, and hence the range should be considered illustrative and not definitive. Nevertheless, this analysis shows that existing carbon taxes appear to have noticeable but not dramatic effects on energy use and carbon emissions. This range is for carbon taxes that on average apply to only about half of emissions. If all emissions were covered and reductions were linear with the tax, we would expect these impacts to roughly double.

Our review of previously published studies found studies with ex post information on eight jurisdictions. Table 5 summarizes these findings and also includes our calculation of the average reduction in energy or carbon intensity per year. Only a few studies examined changes in energy use due to the carbon taxes. In Australia the tax reduced electricity use by 1–2%. In the Netherlands the tax reduced residential electricity and natural gas use by 8% and 4%, respectively. Finally, in British Columbia and Ireland, transport fuel use reductions were 2–19%. One of these studies (Rivers and Schaufele 2012) found that the impact of the carbon tax on transportation energy use and emissions was greater than they had expected and that a carbon tax may have particular salience for transportation energy use. They wondered whether consumers are motivated by a desire to reduce emissions as well as by price.

More studies looked at changes in carbon emissions, and all of these studies found declines in carbon emissions due to carbon taxes. Emissions declines at a national level ranged from about 2% (in the United Kingdom and, according to one study, in Norway) to as much as 9% (the upper end of the 5–9% range found for British Columbia). Seven studies provided an estimate of the impact on overall carbon emissions, with the median finding of these studies being a decline of 4%. (We provide this number as an indication; the sample size is too small and the studies are too varied for this to have any statistical meaning.) Some of these studies looked at a single year only, and none of the studies in table 5 looked at a period of longer than eight years. In table 5 we calculate the average reduction per year, with annual declines ranging from 0.2% to 4.0%. The high numbers all represent short-term studies covering only a year or two. The median decline per year was 1.3%.

To put these figures in context, in the recently concluded Paris climate agreement, nations agreed to reduce their emissions by 80% or more. A reduction of 4%, while helpful, is a drop in the bucket. If we apply the median reduction per year (1.3%), it would take over 110 years to reach the 80% emissions-reduction target. Of course, taxes could be higher than the levels now in place, coverage could be greater, or future analyses could show somewhat higher impacts, but given the information we have available, it is unlikely that taxes at current levels and coverage will satisfy the 80% emissions-reduction goal in a reasonable period of time. Several of the studies looked at impacts in the industrial sector. Enevoldsen (2005) found that in Denmark the carbon tax reduced industrial carbon emissions by 9–11%. Voluntary agreements spurred by tax reductions saved additional energy, but the tax reductions were modest, and hence the tax had a large impact. In contrast, studies on the Netherlands and the United Kingdom found that the carbon tax reduced industrial emissions by only 1–2%, because firms could avoid all or most of the tax by entering into voluntary agreements. Voluntary agreements can reduce industrial-firm opposition to carbon taxes, but they must be constructed with care.

Table 5. Summary of study results in different jurisdictions

Province/ country	Reduction	Metric	Year(s)	Avg. decline/ year	Notes
British Columbia	5–9%	CO_2 emissions	2007–14	1.0%	
	2–19%	Gasoline use	2007–14	1.5%	
Australia	8%*	CO_2 emissions	2012–14	4.0%	
	1–2%	Electricity use	2012–14	0.8%	
Norway	3–4%	CO_2 emissions	1991–93	1.8%	
	2%	CO_2 emissions	1990–94	0.5%	Low impact due to extensive exemptions, limited elasticity
Sweden	3–5%	CO_2 emissions	1991–94	1.3%	
	0.8–2.5%	CO_2 emissions	1991–95	0.4%	
	10%	GHG excluding transport	1991–94	3.3%	
Denmark	9–11%	Ind'l GHG	1992–2000	1.3%	
Nether-lands	1–2%	Ind'l GHG	1992–2000	0.2%	Other policies had more impact since the tax is waived for large firms that enter into agreements.
	8%	Resid'l elec.	1994–99	1.6%	
	4%	Resid'l nat. gas	1992–99	1.0%	Demand not very elastic
Ireland	7%*	GHG emissions	2011	1.5%	
	8–9%*	Transport fuel	2010–2011	4.0%	
United Kingdom	2%	GHG emissions	2002	2.0%	Reduced fees for companies with agreements; agreements increased energy intensity and expenditures

* These estimates are not adjusted for the relative impact of carbon taxes versus other factors.

We find several jurisdictions where carbon taxes appear to have spurred some switching to lower-carbon energy sources. In Australia renewable-energy and natural gas use increased and coal use decreased during the carbon tax period; coal use began to rebound when the tax ended. Similarly, in Sweden the tax appears to have spurred a shift toward use of biomass in the district heating sector.

In terms of further work needed, most of these studies cover only a few years. More work is needed to look at the long-term impacts of carbon taxes. For example, the Danish carbon tax reduced industrial emissions by 9–11% over an eight-year period. Do these savings continue growing over longer periods, or do the savings level off or even decline? In particular, the Nordic countries and the Netherlands have had carbon taxes since the early 1990s, but most of the studies available look only at the 1990s. Lin and Li (2011) looked at 17 years of data and, except in Finland, did not find statistically significant differences in carbon emissions, indicating either that the effects may trail off after many years and/or that separating out the effects of a carbon tax from other changes over such a long period is very difficult. More studies of the past 15 or so years, looking at impacts of carbon taxes on energy use and emissions and at the impacts of other explanatory variables, would be very useful. While long-term studies can be difficult to conduct, as they require controlling for changes in many factors, they will be helpful for understanding the role of carbon taxes in long-term emissions-reduction strategies.

In addition, more studies are needed on the residential and commercial sectors in particular. There is only one study on the commercial sector (in British Columbia), but the implied emissions reduction for the one fuel studied, natural gas, was so high that the authors did not report the savings number and instead simply noted that the savings were statistically significant. In the residential sector, energy-use reductions ranged from 4 to 15%; further studies are needed to narrow this range and also explore whether residential electricity use is more sensitive to a carbon tax than residential natural gas use (as found by Berkhout et al. 2004).

While studies to date are limited, it is notable that every study we looked at found that carbon taxes reduce energy use and emissions relative to periods and/or countries without carbon taxes. So far the impacts have been modest. Still, carbon taxes can be combined with other strategies to spur substantially larger emissions reductions. The studies we reviewed for Australia, Denmark, the Netherlands, and Ireland all show how various strategies can be combined to result in larger reductions. We tentatively conclude that carbon taxes can be a useful strategy, but at the tax levels that have been politically feasible thus far, carbon taxes alone are unlikely to solve the climate change problem.

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