CARBON TAX EFFECTIVENESS: AN ECONOMIC ANALYSIS

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Abstract

Carbon taxes are becoming one of the most common ways to reduce greenhouse gas emissions. However, the true efficacy of carbon taxes is often debated. This paper will study how carbon taxes affect emissions by using fixed effect panel regression analysis on eight different countries from 2000-2019. The results suggest that a one USD increase in the carbon tax rate leads to a 0.14% decrease in greenhouse gas emissions. These findings indicate that carbon taxes are effective in reducing emissions, but that much more is needed to reach emissions goals, and combat the effects of climate change.

KEYWORDS: (Carbon pricing, Carbon tax, Greenhouse gas emissions, Climate change)

JEL CODES: (Q480, Q580)

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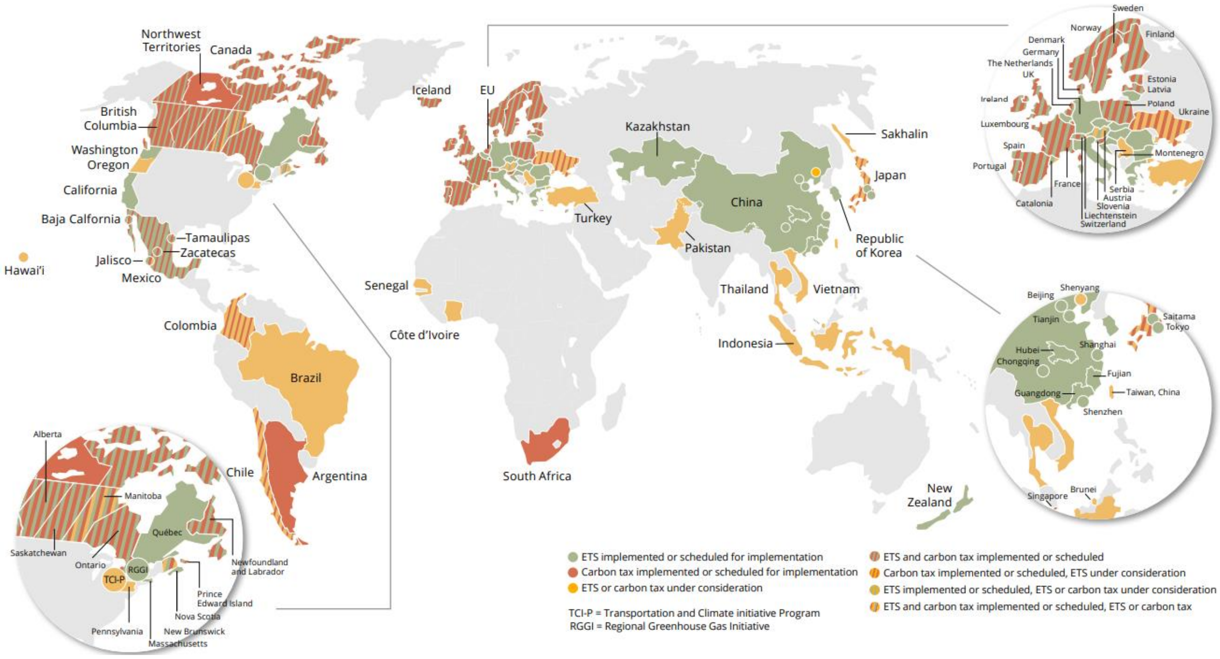
Introduction

Climate change is likely the greatest global issue in the foreseeable future. One of the best ways to reduce the severity of climate change is to reduce greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC) claims that we must reduce emissions as fast as possible in order to avoid the most severe effects of climate change (IPCC, 2022). Specifically, the IPCC claims we must reduce emissions by 43% by 2030 in order to reach their goal of limiting warming to 1.5°C. One of the simplest and most common ways to reduce emissions is carbon pricing. GHG emissions cause all sorts of environmental and health problems that the emitters often ignore. Carbon pricing is a way to capture these externalities by putting a price on emissions. This can be done in many ways but is generally either an emissions trading system (ETS) or a carbon tax. ETSs work by setting a specific limit on emissions and institutions receive allowances if they are below the allowed emissions. Institutions that emit more than the limit must trade for allowances. Carbon taxes put a specific price on either emissions or fuels that cause GHG emissions. The benefit of ETSs is that they will always reduce emissions by a set amount, while the price of allowances will vary based on the emissions trading market. Carbon taxes, on the other hand, are much easier to implement, but regulated institutions can pay the tax and continue to emit (Green, 2021). Another major benefit of carbon pricing is that it can provide revenue for the government. Goulder (2013) claims that carbon taxes can "produce a double dividend — both reduce greenhouse gas emissions and lower the costs of the tax system." This revenue gained from these taxes can go towards reducing individual taxes, as well as towards policies that further help reduce emissions or solve climate issues. In 2020 alone, carbon pricing policies generated $53 billion in revenue around the world (World Bank, 2021).

Figure 1.1

Global Map of Carbon Pricing



Source: World Bank, (2021)

As of 2023, there are 70 carbon pricing initiatives already implemented and many more under consideration around the world (World Bank, 2023). Figure 1.1 shows all the carbon pricing initiatives in place or under consideration in 2021. As so many countries already have carbon pricing, or are working towards it, it is important to study the effectiveness of these policies. While most literature agrees that carbon pricing is important to some extent, they often argue their efficacy in relation to other policies.

Since ETSs are more difficult to compare across different countries, this paper will focus specifically on carbon taxes. This paper will use panel regression analysis, creating models that estimate the effect of each variable on GHG emissions. Carbon tax rate will be the key independent variable, and the control independent variables will include household consumption, capital formation, renewable energy consumption, and urbanization percentage. It will look at carbon taxes across seven European countries, as well as Japan, from 2000-2019. It is hypothesized that carbon tax rates are shown to reduce GHG emissions, but based on previous research, the reductions may be small, and not enough to significantly reduce emissions.

It is important to explore this relationship to inform policymakers around the world. Seeing as so much time and effort is being put towards carbon pricing initiatives, knowing the full effects of these policies will be very beneficial in their decision making. If a country is trying to reduce their GHG emissions by a specific amount, is it realistic for them to get there by using only a carbon tax? How much would a small increase in carbon tax rates affect emissions? With current policies in place would it be possible to reach the IPCC's goals of reducing emissions? The regression in this paper will give a rough answer to these questions.

This paper will explore the literature and arguments about the efficacy of carbon taxes, as well as the different economic models used to measure them. The methodology section will explain the detail behind the countries and variables used, and the process of the regression analysis and the theory behind it. Finally, this paper will present and discuss the results of the regression analysis and the limitations and implications of those results.

Literature review

While almost all the literature agrees that carbon taxes are good to some extent, their effectiveness and role in our environmental policy is much more debated. Many non-empirical studies and analyses argue that carbon taxes are the absolute minimum and will not do enough to reduce emissions and meet decarbonization goals. Rosenbloom et al. (2020) critiques carbon pricing by claiming it is too focused on economics rather than climate change. They argue that carbon taxes are focused on efficiency for polluters rather than effectiveness in reducing emissions. Instead, they believe that we need to push for more transformative change, and that carbon pricing should be a small part of a larger, more targeted systemic solution (Rosenbloom et al., 2020). Many other studies agree with this idea that carbon pricing is not enough. Tvinnereim & Mehling (2018) claim that there has not been evidence that carbon pricing produces “deep decarbonization” which is necessary to meet emissions goals. They concede that carbon pricing “can provide revenue for other measures and serve as a backstop policy to incentivize abatement in areas that more targeted instruments are unable to reach,” but their main argument is that much more is needed (Tvinnereim & Mehling, 2018). Since climate change is such an urgent problem, this type of thinking is very understandable. There needs to be systematic change and something as simple as taxing carbon emissions may not do enough.

However, there is still a major role for carbon taxes, and they should not be dismissed. Van den Bergh & Botzen (2020) responding directly to Rosenbloom et al. (2020), claim that carbon pricing is “a prime example of systemic policy: It simultaneously shifts choices of consumers, producers, investors, and innovators in all sectors—essential to a low-carbon transformation.” They agree that more policies are needed but emphasize the importance of carbon pricing in beginning emissions reductions and easing the transition to more policies.

Carbon pricing is also praised for its low cost and ease of implementation, as well as its ability to cover every polluter (Baranzini, 2017).

This debate continues in more empirical data-based studies as well, as the effectiveness of carbon taxes has had conflicting results. Green's (2021) review analysis found that carbon pricing generally leads to anywhere from 0%-2% reduction in emissions. Hajek et al. (2019) found that a 1 Euro increase in a carbon tax (per ton of CO_2 emissions) would reduce emissions by 11.58 kgs per year. If assuming a reasonable but large 20 EUR per ton tax (21.2 USD), this would result in a decrease of about 5% in per capita emissions when using global per capita emissions. While this varies greatly by country and price of tax, many countries have a tax of 20 Euros or more, and this would be much greater than what Green (2021) suggested. This is an oversimplification but certainly shows the variability of carbon tax evaluations.

Another regression analysis looking specifically at Sweden, who has had some of the highest carbon tax rates, found that the overall emissions reductions from the carbon tax were anywhere from 200-800 kgs per capita (Runst & Thonipara, 2019). This study used a difference in difference (DiD) regression to create a control group of countries that did not have carbon taxes and measured that group against Sweden. They found significant changes in emissions due to the carbon tax and claimed that the high tax rate in Sweden was largely the cause (Runst & Thonipara, 2019). Lin & Li (2011) also performed a DiD regression analysis and had different results. Looking at five different European countries, only Finland was found to have a 1.69% reduction in per capita emissions. The reductions in all the other countries were not statistically significant.

In a review article looking at many different carbon tax evaluations, Leu & Betz (2016) claim "a significant effect on the amount of CO2 emissions can be detected, however, it is sometimes difficult to assign the effect to the tax since other effects are more important or the tax is too low in order to clearly assign variations in the emissions to the tax." They have some problems with DiD regression analyses when studying carbon taxes and while it may sometimes work, there are many things that can go wrong and aren't always accounted for (Leu & Betz, 2016).

Hajek et al. (2019) agree that Lin & Li's (2011) DiD regression analysis is flawed and instead they chose a panel regression analysis with fixed effects to evaluate similar countries. They found a much greater effect on those countries than Lin & Li (2011). Specifically, they used data from 2005-2015 on Denmark, Ireland, Finland, Sweden, and Slovenia. With CO2 tax rates as their main independent variable, they also included the control independent variables: emission allowance price (in relation to EU ETS), household final consumption expenditure, corporate investments, solid fuel consumption, and renewable energy consumption.

This paper will attempt to build on Hajek et al. (2019) by adding more countries, years, and variables which will be discussed in depth in the next section.

Methodology

Data

As carbon taxes are only a small part of what causes a reduction in GHG emissions, carbon tax rate (in 2023 USD per ton of CO_2 emissions) is the key independent variable with control independent variables being household final consumption expenditure (USD per capita), gross fixed capital formation (USD per capita), renewable energy consumption (% of total energy consumption), urbanization percentage. CO_2 emissions, the dependent variable, was measured in tons per capita. All these data were collected from the World Bank with the exception of CO_2 tax rates, which were found through a variety of sources. Full tables of CO_2 tax rates, and all their sources are displayed in the Appendix Tables A1 and A2. There were also indicator variables used to account for which sectors and fuels were covered by each tax. A list of all variables is given in Table 3.1 and more information about the indicator variables can be found in the notes section of Table 3.2.

Table 3.1

Variable Names and Descriptions

Variable	Abbreviation	Units	Expected effect on GHG emissions
GHG emissions	GHG	Tons of CO_2 emissions per capita	
Carbon tax rate	Tax	$ per ton of CO_2	Negative
Household final consumption expenditure	H	$ per capita	Positive
Gross fixed capital formation	CF	$ per capita	Negative

Renewable energy consumption	R	% of total energy consumption	Negative
Urbanization percentage	U	% of population	Positive
Tax includes industry sector	I	Binary indicator	Negative
Tax includes all sectors	A	Binary indicator	Negative

Source: Own calculations

Since the data on tax rates were collected from a variety of different sources, there were a lot of inconsistencies. Many sources were inconsistent due to exchange rates and inflation. To account for this, the rates were collected in the countries' currency then converted to current (2023) USD. Due to these inconsistencies and a lack of data on the exact carbon tax rates, some years from Denmark (2016-19) and Finland (2000-10, 2016-19) were excluded.

These variables are very similar to what Hajek et al. (2019) used. Household final consumption expenditure was the same as what they used. Gross fixed capital formation was used to represent their capital investment variable. Instead of separate variables for solid fuel consumption and renewable energy consumption, renewable energy consumption as a percentage of total energy consumption was used.

Lin & Li (2011) used similar variables in their regression. They also had urbanization level which was insignificant in their study likely due to the fact that they researched very similar countries (Nordic countries only). Urbanization percent was used in this study to see if the addition of non-Nordic countries would change the significance of urbanization on GHG emissions.

The years selected for this study were 2000-2019. The purpose was to get more data than the Hajek et al. (2019) study but ending in 2019 to avoid inconsistencies caused by the COVID-19 pandemic. Since so many things were shut down by the pandemic, there could likely be a sharp decrease in emissions, and then an increase in more recent years as things opened up. Ending in 2019 avoids these major disruptions. The countries selected include the same five that were used in Hajek et al. (2019) with the addition of Japan, France, and Portugal. Table 3.2 displays each country used and the 2019 tax rates for each country, year of implementation, as well as what sectors are covered by the tax and additional notes.

Table 3.2

Countries Included in Analysis

Country	2019 Tax rate (Current USD per Ton of CO_2)	Year of implementation	Notes
Ireland	$24	2010	Covers all sectors.
Sweden	$139	1991	Covers building and transport sectors.
Slovenia	$21	1996	Covers building and transport sectors.
France	$54	2014	Covers building, transport, and industry sectors.
Japan	$2	2012	Covers all sectors.
Portugal	$29	2015	Covers building, transport, and industry sectors
Finland	$23 (2015)	1990	Covers building, transport, and industry sectors. Does not include peat.
Denmark	$16 (2015)	1992	Covers building and transport sectors

Sources can be found in Appendix table A1

Summary statistics for all the continuous data can be found in Table A3 in the appendix.

Theory

Equation 3.1 represents the linear regression used to model the effect of the independent variables on GHG emissions.

$$GHG = \beta_0 + \beta_1 TAX + \beta_2 H + \beta_3 CF + \beta_4 R + \beta_5 U + \beta_6 I + \beta_7 A + \varepsilon \qquad (3.1)$$

Where the coefficients $\beta_{1\ldots5}$ are the effects of each continuous independent variable on GHG emissions and $\beta_{6,7}$ are the effects of the binary indicator variables. β_0 is the intercept term and ε is the error term . Based on the main hypothesis of this paper, it was predicted that β_1 would be negative because higher tax rates should result in lower emissions. Hajek et al. (2019) predicted that household final consumption expenditure was going to have a positive effect and corporate investment was going to have a negative effect on GHG emissions (β_2 was expected to be negative and β_3 positive). Both were shown to be close to zero and the opposite sign than predicted in their analysis. With more data, this regression was expected to have the same signs as their original prediction. Household final consumption expenditure was hypothesized to have a positive effect on emissions because the more spending at the household level would lead to more economic activity and therefore higher emissions. Therefore β_2 was predicted to have a positive sign. Since there is not a good way to measure investment in green technology, gross fixed capital formation was used by Hajek et al. (2019), and in this regression. This is far from a perfect substitute for green investment, but it was used as a representation and was expected to have a negative effect on GHG emissions. β_3 was thus expected to have a negative sign. Renewable energy consumption percentage was predicted to have a negative effect on emissions because the more renewable energy a country uses, the less per capita emissions they should have. Lastly, Urbanization percentage was predicted to have a positive effect on emissions because generally urban areas produce more emissions. The indicator variables describe which sectors are covered by the tax. All taxes cover the transport and building sectors so I is true (takes a value of 1) if the tax covers industry as well, and A is true if the tax covers all sectors. Since these indicator variables increase the strength of the tax, it was expected that β_6 and β_7 would both be negative.

While originally theorized that emissions and tax rates would have a linear relationship (equation 3.1), it is very possible that this relationship is non-linear. An exponential model is given in equation 3.2 where everything remains the same with the addition of the tax rate squared as a variable. The semi-log model is given in equation 3.3 where the natural log is taken of the dependent variable (Dranove, 2012).

$$GHG = \beta_0 + \beta_1 TAX + \beta_8 TAX^2 + \beta_2 H + \beta_3 CF + \beta_4 R + \beta_5 U + \beta_6 I + \beta_7 A + \varepsilon \qquad (3.2)$$

$$\ln(GHG) = \beta_0 + \beta_1 TAX + \beta_2 H + \beta_3 CF + \beta_4 R + \beta_5 U + \beta_6 I + \beta_7 A + \varepsilon \qquad (3.3)$$

The hypothesized signs of the coefficients in these equations remain the same as equation 3.1. β_8 was predicted to be negative, because as the tax increases, there would be a greater marginal effect on greenhouse gas emissions.

These three models were run using a fixed effects panel regression. A fixed effects regression was used to keep consistent with Hajek et al. (2019) and to account for unobserved policy or cultural differences in each country. Then, regressions were run for each individual countries with the exception of Finland because of the smaller sample size.

Results

All three panel fixed effects regression models are displayed in Table 4.1.

Table 4.1

Panel Fixed Effects Regressions

Variables	Linear GHG	Exponential GHG	Semi-log lnGHG
Intercept	7.329***	9.317***	2.436***
	(1.753)	(1.563)	(0.193)
Tax rate	-0.00250	-0.0580***	-0.00144***
	(0.00437)	(0.00955)	(0.000482)
Tax rate squared	-	0.000337***	-
	-	(5.31e-05)	-
Household final consumption expenditure	-1.12e-05	-2.24e-05*	1.36e-07
	(1.44e-05)	(1.27e-05)	(1.59e-06)
Gross fixed capital formation	5.69e-06	1.61e-05	1.45e-06
	(1.31e-05)	(1.15e-05)	(1.44e-06)
Renewable energy consumption	-0.204***	-0.215***	-0.0297***
	(0.0137)	(0.0121)	(0.00151)
Urbanization percentage	0.0569**	0.0403*	0.00131
	(0.0260)	(0.0229)	(0.00287)
Tax includes industry sector	-0.202	1.297***	-0.00797
	(0.234)	(0.313)	(0.0258)
Tax includes all sectors	-0.880***	-0.143	-0.0353*
	(0.183)	(0.197)	(0.0201)
R-squared	**0.796**	**0.846**	**0.874**

Source: Own calculations

*** p<0.01, ** p<0.05, * p<0.1, standard errors in parentheses.

Tax rate was only statistically significant ($p<0.1$) in the exponential and semi-log models. In all models, the coefficient for tax rate is negative, supporting the hypothesis that a higher tax rate would lead to lower GHG emissions. Renewable energy consumption was significant and negative in all equations, as expected. The other variables were much more varied. Consumption was positive, as hypothesized, in the semi-log model but negative in the other two and only statistically significant in the exponential model. Capital formation was positive but not significant in all models, meaning that in all models, the coefficient for this variable was not statistically different from zero. Urbanization percentage was positive and significant in the first two models, consistent with the hypothesis, but not significant in the semi-log model.

The indicator variables were not consistent across models. In the linear and semi-log models, the “Tax includes all sectors” variable was statistically significant and negative, supporting the hypothesis, but the “Tax includes industry sector" variable was insignificant. In the exponential model, the “Tax includes industry sector” variable was statistically significant but not the “Tax includes all sectors” variable. The “Tax includes industry sector” variable had a positive estimated coefficient in the exponential model, which is inconsistent with the hypothesis.

While all models are helpful in understanding the relationship between carbon tax rates and greenhouse gas emissions, the semi-log model was found to show the best relationship between tax rates and emissions of the three models. The semi-log model has the highest R squared value (0.874), meaning that variation in the independent variables in this model account for 87.4% of the variation in GHG emissions. The correlation coefficient between tax rates and the natural log of emissions (-0.53) was higher than the correlation between tax rates and emissions (-0.49) and tax rates squared and emissions (-0.49). This means that the strongest relationship was between the natural log of GHG and tax rates.

Some of the other independent variables were also correlated. Renewable energy percentage was highly correlated with tax rates, with a correlation coefficient of .79 (anything above .7 is considered to be highly correlated). There were correlations between consumption, capital formation, and urbanization as well. These were still included in the model to keep consistent with Hajek et al. (2019). The full correlation matrix can be found in Appendix Table A4.

Regressions were also run for each individual country with the exception of Finland because there were only four observations for Finland. Indicator variables were not included in these regressions because for each country that had an indicator variable, the variable was true for all years that the tax rate was not zero. Therefore, on a country level, the indicator variables are redundant. Country regression results can be seen in Table 4.2.

Table 4.2

Individual Country Regressions

Variables	Denmark lnGHG	France lnGHG	Ireland lnGHG	Japan lnGHG	Portugal lnGHG	Slovenia lnGHG	Sweden lnGHG
Intercept	12.73	6.994***	0.0219	2.171***	3.914***	5.007***	9.392***
	(11.21)	(1.551)	(3.249)	(0.410)	(0.710)	(0.542)	(1.337)
TAX	-0.118*	0.000564	-0.00459*	0.0342***	0.00384**	0.00636	-0.000235
	(0.0638)	(0.000946)	(0.00239)	(0.00982)	(0.00167)	(0.00977)	(0.000549)
H	-1.50e-05	-8.35e-07	-7.75e-06	-3.37e-06	1.69e-05	2.07e-05*	4.75e-08
	(1.21e-05)	(1.55e-05)	(4.68e-06)	(8.92e-06)	(1.55e-05)	(9.78e-06)	(6.48e-06)
CF	3.19e-05*	7.81e-06	4.73e-06**	6.01e-06	-1.50e-05	1.01e-05	-5.61e-06
	(1.55e-05)	(3.07e-05)	(1.76e-06)	(2.33e-05)	(3.04e-05)	(1.11e-05)	(1.26e-05)
R	-0.0402***	-0.0107	-0.0538***	-0.0478***	-0.0193***	-0.0195**	-0.0123***
	(0.00951)	(0.00877)	(0.0163)	(0.0135)	(0.00397)	(0.00782)	(0.00374)
U	-0.0879	-0.0671***	0.0434	0.00318	-0.0328**	-0.0579***	-0.0843***
	(0.123)	(0.0217)	(0.0561)	(0.00501)	(0.0137)	(0.0122)	(0.0173)
R-squared	**0.971**	**0.964**	**0.969**	**0.611**	**0.960**	**0.918**	**0.982**

Source: Own calculations
*** p<0.01, ** p<0.05, * p<0.1, standard errors in parentheses. Finland not included due to lack of observations.

The results are much more varied here. Tax rate is only significant about half the time, and is positive for some of these countries as well. Renewable energy percent is significant for every country except for France and is negative for all countries, as predicted. The rest of the variables all vary in significance and sign. Despite all the variability, these generally have very high R-squared values (.910 avg), indicating that these variables were good at predicting the changes in GHG emissions.

Discussion

According to the semi-log model, a $1 increase in the carbon tax rate leads to a 0.14% decrease in GHG emissions. If assuming global per capita emissions levels, this would be a decrease of 6 kgs per capita for every $1 increase in the tax rate. This is about half of what Hajek et al, (2019) found, and similar to estimates found by Green (2021) and Lin & Li (2011). However, there are many limitations to these findings.

Since tax rate was significant in both the exponential and semi-log models but not the linear model, it is possible that tax rate has a non-linear relationship with emissions. With these data, the models indicate that there is in fact a non-linear relationship between these two variables. However, a potential problem with the data for tax rates was that all the tax rates were adjusted for inflation. Since the units for all tax rates were in 2023 USD, inflation affected otherwise unchanging tax rates. For example, the tax rates in Japan remained at 2.89 JPY for all years that they had a carbon tax, but when converted to 2023 USD, the tax rate decreases every year due to inflation. Detailed tables on tax rates in the countries original countries and converted to 2023 USD can be found in the Appendix Tables A1 and A2. This can explain why tax rates are positive or insignificant in a lot of the individual country regressions. Many countries reduced per capita emissions most years, but the tax rates remained relatively unchanged. These units were chosen to keep consistent with consumption and capital formation, which were also in 2023 USD. This could also help explain why in the exponential model, the square of the tax rate had a positive coefficient. It was predicted that as tax rates got higher, each additional increase in rates would lead to a larger decrease in emissions. This was not the case in the exponential model that was created, and this could perhaps be explained by the units of the tax rates. Despite this being a potential problem, the semi-log model worked with the data, so it is possible that using a semi-log model accounted for this problem.

Consumption, capital formation, and urbanization are very inconsistent across the different panel and individual regressions. This can be partially explained by the correlations between these variables. Consumption and capital formation were both insignificant in the semi-log model indicating another possible limitation of that model.

Urbanization percentage was not significant in the semi-log models, but it was significant in the linear and exponential models. In the individual regressions, urbanization was significant for four countries and negative in all four. This contradicts the hypothesis that more urbanization leads to higher emissions, indicating that the opposite may be true for some countries. Due to the variability in results for urbanization in this thesis and in past models (Lin & Li, 2011), further research needs to be done to better understand the effect of urbanization on emissions.

Renewable energy consumption is almost always significant and negative as expected. Clearly, as countries use more renewable energy, their emissions appear to decrease. Renewable energy percentage was also correlated with tax rates. Countries with higher tax rates are likely to have stronger environmental policies and therefore more renewable energy. Despite this correlation, it was important to keep renewable energy in the model because of its statistical significance, and the large role renewable energy plays in reducing emissions.

The indicator variables were also very different across the three different panel models. They were included to attempt to group countries based on how the tax works. However, due to the small number of countries, the "Tax includes industry sector" indicator variable was only true (assumed a value of one instead of zero) for three countries, and the "Tax includes all sectors” variable was only true for two countries. If there were more countries, the indicators would have likely been more significant across all the models.

Additional limitations include the countries selected in this model. Due to a lack of data and time, only 8 countries were able to be included in this regression. It is also difficult to study some countries as the way carbon is taxed varies greatly. Countries such as Mexico would have been included, but their tax rate is different for each fuel, and it was harder to standardize it and compare Mexico’s tax to other countries’ taxes.

Further research should include more countries and years to get a broader picture. More countries have been implementing carbon taxes, and recent data is becoming available. This will make it much easier to conduct a broader study and learn more about carbon taxes. Research should also focus on studying non-European countries, as many studies including this one, mainly study Europe’s carbon taxes. Further research could also study how the combination of carbon taxes, and the revenues from carbon taxes, go towards reducing emissions. This study only looks at the direct effects of the carbon tax and does not measure how revenues from carbon taxes could indirectly go towards other policies aimed at reducing emissions.

Despite the limitations, there is much that can be learned from these models. The results of this analysis seem to support the idea that carbon taxes are effective, but not enough. If countries want to reduce emissions by 43%, following the IPCC’s recommendation (IPCC, 2022), countries would need a tax rate of 307 USD according to the semi-log model. This is not realistic, as no country currently has a tax rate this high, and it is unlikely that any country would have taxes this high by 2030. Carbon taxes are important and can be a great first step, but it seems that more is necessary. Based on the data, these taxes do not lower emissions enough to realistically make a big enough difference. Policy makers should certainly implement carbon taxes, but they also should focus on other policies as well. These could include ETS's, stricter regulations on heavy emitters, subsidies for renewable energy, and cutting out natural gas and coal. Carbon taxes can be a good start for beginning to lower greenhouse gas emissions but must be combined with these types of policies to seriously reduce the effects of climate change.

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Appendices

Table A1

Tax Rates in Countries' Nominal Currency

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Denmark (DKK)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	-	-	-	-
Finland (EUR)	-	-	-	-	-	-	-	-	-	-	-	18	18	18	18	18	-	-	-	-
France (EUR)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	14.5	22	30.5	44.6	44.6
Ireland (EUR)	0	0	0	0	0	0	0	0	0	0	15	15	20	20	20	20	20	20	20	20
Japan (JPY)	0	0	0	0	0	0	0	0	0	0	0	0	289	289	289	289	289	289	289	289
Portugal (EUR)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	24	24	24	24
Slovenia (EUR)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	17.3	17.3	17.3	17.3
Sweden (SEK)	370	530	630	760	910	910	920	930	1010	1050	1050	1050	1050	1050	1050	1150	1150	1150	1150	1180

Sources Scharin & Wallström, (2018), Douenne (2021), Paradiz & Kranjc, (2002), Republic of Slovenia (2020), Jonsson et al. (2020), Carbon Tax Center, (2020), Rocamora (2017)

Table A2

Tax Rates in Current (2023) USD

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Denmark	21.4	20.9	20.4	20.0	19.8	19.4	19.0	18.7	18.1	17.9	17.5	17.0	16.6	16.5	16.4	16.3	-	-	-	-
Finland	-	-	-	-	-	-	-	-	-	-	-	24.0	23.4	23.1	23.0	22.9	-	-	-	-
France	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.9	18.4	27.9	38.1	54.6	53.8
Ireland	0	0	0	0	0	0	0	0	0	0	20.5	19.9	26.0	25.5	25.4	25.4	25.4	24.9	24.5	24.2
Japan	0	0	0	0	0	0	0	0	0	0	0	0	2.4	2.3	2.3	2.3	2.3	2.3	2.2	2.2
Portugal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.5	30.4	29.9	29.4	28.9
Slovenia	25.1	24.6	24.0	23.5	23.0	22.5	22.0	21.5	20.9	20.8	20.5	19.9	19.4	19.2	19.1	19.1	21.9	21.6	21.2	20.9
Sweden	55.8	77.9	90.6	107.3	128.0	127.4	127.1	125.7	131.9	137.8	136.3	132.3	131.2	131.2	131.5	144.1	142.7	140.2	137.5	138.6

Sources: Inflationtool.com, own calculations.
Exchange rates used: 1 DKK = 0.14 USD, 1 EUR = 1.06 USD, 1 JPY = .0073, 1 SEK = .096 USD

Table A3

Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
GHG	141	7.206	2.106	3.405	11.593
lnGHG	141	1.931	.303	1.225	2.45
TAX	141	27.862	41.706	0	144.067
TAX^2	141	2503.377	5734.673	0	20755.357
H	141	19335.482	6124.252	5744.802	30483.29
CF	141	9052.344	4989.94	2761.536	43946.936
R	141	19.252	13.69	1.97	52.88
U	141	73.215	13.825	50.754	91.698

Source: Own calculations

Table A4

Correlation Matrix

Variable	GHG	lnGHG	TAX	TAX2	H	CF	R	U
GHG	1.000							
lnGHG	0.990	1.000						
TAX	-0.487	-0.529	1.000					
TAX^2	-0.485	-0.538	0.971	1.000				
H	0.108	0.069	0.238	0.269	1.000			
CF	0.182	0.155	0.223	0.229	0.681	1.000		
R	-0.631	-0.652	0.794	0.756	0.107	-0.014	1.000	
U	0.017	-0.019	0.305	0.342	0.681	0.325	0.179	1.000

Source: Own calculations