Econ 140 Replication Project

Carbon Taxes and CO2 Emissions: Sweden as a Case Study by Julius J. Andersson

Toby Wu, Joe Kirsten, Ty Wolber, Joel Yamada

Introduction:

In 2015, as a part of the Paris Agreement–an international treaty on climate change–each country put forth a "contribution" effort towards possible mitigation policies to limit global warming. Most of these policies revolved around pricing the effects of greenhouse gas emissions like carbon dioxide (CO_2). This was done through two possible implementations: issuing tradable emissions permits, commonly referred to as cap-and-trade, or through a carbon tax. While most economists favor a price policy in the form of a tax, there are many issues surrounding its application. Public support for a tax is generally lower than an emissions cap, as many believe that they are environmentally inefficient. However, when evidence of its efficacy showed that they did have a positive impact on emissions reduction, there was greater support for carbon taxes. Still, few countries have implemented a carbon tax due to these hesitations, and there have been few empirical studies to help garner support for a price policy over a quantity policy. Correctly pricing pollution is important to ensure that the most cost-effective and efficient solutions are being adopted across countries.

The study chosen in this econometric replication project (*Carbon Taxes and CO2 Emissions: Sweden as a Case Study* by Julius J. Andersson) aims to investigate the causal effect of carbon taxes on emissions, analyzing the implementation of a carbon tax and a value-added tax on transport fuel in Sweden. There are few reasons why Sweden was chosen as a location of interest. Firstly, Sweden's location makes it less susceptible to carbon leakage from the transport sector, reducing the chance of estimated emission reductions to be biased. In addition, Sweden only shares a land border with Norway, whose gas prices are on average 15 percent higher. This makes gas price arbitrage less attractive for Swedes. The transport sector was chosen to analyze the carbon tax as it is Sweden's largest source of CO_2 emissions–responsible for close to 40 percent of total annual CO_2 emissions from 1990 to 2005. In addition, it is suitable because the transport sector is fully covered by the carbon tax, whereas other sectors like domestic aviation are exempt from energy, carbon and value-added taxation.

While section I of the study uses a synthetic control method to present the results of the empirical analysis, the portion we are replicating (section IV) deals with finding the effect of a carbon tax to estimate gasoline consumption. To achieve this, the study employs multiple linear regression analyses including a log-linear model for ordinary least squares, and a two-stage least squares regression using instrumental variables. Some factors to predict gasoline consumption per capita include a tax-exclusive gas price, a carbon tax, as well as other control variables like GDP per capita, unemployment rate, and a time trend. Using these variables, the study aims to determine the effect of a carbon tax on gasoline consumption to see if there is any efficacy as an instrument for future carbon tax policies.

There are a few limitations that should be considered when looking at this study. One significant limitation is the generalizability of the findings, as the study is conducted based on Swedish context. The effectiveness of carbon taxes in Sweden may not be directly applicable to other countries with different social, political, and economical contexts. Another potential limitation is the effectiveness of carbon taxes in reducing CO_2 emissions may vary over time. A longer-term analysis and data collection study could lead to a more comprehensive understanding of the impact of such policies. Andersson points out that there can be several issues using the synthetic control method. Especially with the gasoline market, it points out that consumers tend to respond more significantly to tax changes than to equivalent price changes. Also studies have shown that tax elasticity is two and a half to four times larger than the price elasticity, which means simulations that rely on price elasticities of demand may underestimate the true impact of carbon taxes on CO_2 emissions. Even though the synthetic control method has multiple advantages over methods like difference in difference estimators (DiD), there are still some limitations. The synthetic control methods may not be as effective when there is only one treated unit, as it relies on creating a counterfactual based on a combination of control units. The estimated coefficient of the transport emissions from the Swedish carbon tax and the VAT are almost identical, which could present the endogeneity of gasoline prices. Also, technological advancement and changes in consumer behavior can adjust CO_2 emissions.

Following the introduction of a carbon tax and VAT on transport fuels in Sweden, Andersson found a decrease of nearly eleven percent in CO_2 emissions from transport on average per year, with six percent from the carbon tax alone. Additionally, this paper finds consumers respond more strongly to changes to the carbon tax rate than equivalent gasoline price changes.

The estimated carbon tax elasticity of demand for gasoline was found to be approximately three times larger than the price elasticity. This finding can suggest that with future climate change policies, carbon taxes would be more effective reducing greenhouse gas emissions and air pollution.

Methodology:

The study gathered annual time-series data of the consumption and real price of gasoline in Sweden from 1970-2011. Other source data like the control variables for GDP per capita and unemployment data for Sweden were collected from *Statistics Sweden*, the Swedish government agency operating under the ministry of Finance, responsible for producing official statistics for decision-making, debate and research. The author provided a replication package for this study which compiled this data of regressors for dates between 1970 and 2011 into a .dta file.

The regression model the author used was implemented for OLS:

$$\ln(x_t) = \alpha + \beta_1 p_t^v + \beta_2 \tau_t^v{}_{,CO2} + \beta_3 D_{t,CO2} + X_t\gamma + \varepsilon_t$$

where x_t is gasoline consumption per capita; $p^v{}_t$ is the tax-exclusive gasoline price; $\tau_t^v{}_{,CO2}$ is the carbon tax; $D_{t,CO2}$ is a dummy that takes the value of 1 for years from 1991 and onward and zero otherwise; X_t is a vector of control variables GDP per capita, urbanization, the unemployment rate, and a time trend; and finally, ε_t is idiosyncratic shocks.

Some risk of a biased OLS result can be due to omitted variables, anticipatory effects, or endogeneity–gasoline consumption can affect the gasoline price. While this may pose less of a risk to Sweden due to it being a smaller country compared to larger oil consumers like the US, the issue could still be prevalent. To take these effects into account, a two-stage least squares regression using instrumental variables can help anticipate and mitigate the effects of endogeneity. For the 2SLS regressions, the energy tax rate and the (brent) crude oil price were used as instruments for the carbon tax-exclusive gasoline price. Both pass the relevance condition as the energy tax rate makes up a large part of the carbon tax-exclusive price, as well as the nominal oil price. Also, changes to the energy tax level satisfies the exogeneity condition as it is driven by exogenous changes to environmental policies.

Regression Replication:

To replicate section IV, specifically Table 3 of the study, we regressed gasoline consumption per capita on the decomposed retail price of gasoline (the tax-exclusive price and the carbon tax), a dummy variable that took 1 for years from 1991 (the year the tax was implemented in Sweden) and 0 otherwise, and other control variables: GDP per capita, urbanization, unemployment rate, and time trend.

We used the data set given to us in the replication package provided by Andersson, which compiled statistics from *Statistics Sweden*, annual time-series data of the consumption and real price of gasoline in Sweden from 1970-2011.

We ran four different OLS regressions and two 2SLS regressions. The first OLS regression started with strictly analyzing gasoline consumption on gas price, the dummy variable for carbon tax, and time trend. The following OLS regressions included each of the next variables, cumulative: GDP per capita, urban population, and unemployment rate.

We implemented the following OLS regression model:

$$\mathbf{ln(\hat{Y}) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 x_1} + \boldsymbol{\beta_2 x_2} + \boldsymbol{\beta_3 x_3} + \boldsymbol{\beta_n x_n} + \boldsymbol{\varepsilon_t}}$$

where $\hat{Y}$ is gasoline consumption per capita; x_1 is the tax-exclusive gasoline price; x_2 is the carbon tax; x_3 is a dummy that takes the value of 1 for years from 1991 and onward and zero otherwise; x_n is a vector of control variables GDP per capita, urbanization, the unemployment rate, and a time trend; and finally, ε_t is idiosyncratic shocks. We regress the covariates on the log of $\hat{Y}$, so that our final answer is in terms of a percent change.

For the 2SLS regressions, we used data on the energy tax rate and the (brent) crude oil price as instruments for the carbon tax-exclusive gasoline price. We run it a first time on energy tax rate as the instrumental variable, and a second time with crude oil price as the instrument.

To implement the 2SLS regression using instrumental variables:

1) We regress x_1 on z_1, x_2, x_3, x_n to obtain $\hat{x}_1$

$$\hat{x}_1 = \beta_0 + \beta_1 z_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_n x_n + \varepsilon_t$$

where z_1 is the instrumental variable

2) We plug in the fitted values of $\hat{x}_1$ derived from equation 1 into the original linear regression equation

$$\ln(\hat{Y}) = \beta_0 + \beta_1\hat{x}_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_n x_n + \varepsilon_t$$

We ran our linear regressions in R. Because the replication package with the data provided was in a .dta file (disentangling_regression_data.dta), we used the RStata package to open and read the file. Using the "haven" package in R, we used the function lm() function to run OLS and the ivreg() function to run our 2SLS regression.

After running the code in R, we saw that our replication effort yielded the same results as those in Andersson's study, after accounting for rounding our data to three decimal places. While we didn't encounter many challenges in terms of the regression, we did have to learn how to use the RStata package to access the .dta file in order to use the data included in our regressions.

After viewing both Andersson and our regressions, we see that the conclusions that Andersson made were consistent with what we predicted. In column 4 of our OLS regression, we can see that a one unit change in the tax-exclusive gas price predicted a 6% decrease (as we ran a log-linear regression) in the consumption of gasoline between 1970 and 2011. We can also see that a one unit change in the carbon tax led to a decrease in consumption by around 18.6%. These two numbers illustrate support for Andersson's research question of whether or not a carbon tax has an effect on gasoline consumption. Consumers who consumed gasoline were more price sensitive to a change in the carbon tax, but still sensitive to a change in gas' price. We see that the carbon tax did indeed do its job on limiting gasoline consumption in Sweden during the documented years.

We can also compare our 2SLS regressions for our two instrumental variables–the energy tax rate and crude oil price–with our OLS regression to see if our anticipation of endogeneity between the dependent variables and the independent variables held true. Looking at the tax-exclusive gas price and carbon tax covariates, we see that the coefficients remained relatively the same between all three regressions: column 4–OLS regression, column 5–energy tax rate 2SLS, and column 6–crude oil price 2SLS. We can conclude from this data that our concern about endogeneity, while valid, didn't have much adverse effect on our original OLS regression.

Conclusion:

After looking at our regression results for both OLS and 2SLS, we see that there is generally a negative relationship between a positive change in the tax-exclusive gas price and carbon tax price, and gasoline consumption. The data shows that consumers' price elasticity is higher for the carbon tax price increase versus the price change of gasoline, by a little over three fold. A possible explanation for this could be that consumers generally will never be price sensitive to a change in the cost of gas. Because most people have routine and obligations that require them to drive, most people would not make the trade-off of taking public transit or alternative transportation methods, even if the price of gas were to increase. In addition, changes in the nominal price of gasoline fluctuate daily, and are often short-term. People are not shocked by changes in gas prices, as they experience them every day. In contrast, a carbon tax usually has long-term implications, which can cause people to adopt other practices if they feel the long term consequences will end up costing more than adopting a new way of transportation.

Tables and Figures

(taken from section IV of the paper)

[Original Table 3]

TABLE 3—ESTIMATION RESULTS FROM GASOLINE CONSUMPTION REGRESSIONS

	OLS (1)	OLS (2)	OLS (3)	OLS (4)	IV(EnTax) (5)	IV(OilPrice) (6)
Gas price with VAT	−0.0575	−0.0598	−0.0612	−0.0603	−0.0620	−0.0641
	(0.024)	(0.021)	(0.016)	(0.012)	(0.020)	(0.014)
Carbon tax with VAT	−0.260	−0.232	−0.234	−0.186	−0.186	−0.186
	(0.042)	(0.049)	(0.053)	(0.043)	(0.038)	(0.038)
Dummy carbon tax	0.109	0.0604	0.0633	0.0999	0.0977	0.0949
	(0.040)	(0.061)	(0.061)	(0.066)	(0.070)	(0.059)
Trend	0.0207	0.0253	0.0244	0.0341	0.0342	0.0344
	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
GDP per capita		−0.00108	−0.00105	−0.00366	−0.00367	−0.00368
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Urban population			0.0127	0.0301	0.0313	0.0329
			(0.075)	(0.067)	(0.064)	(0.058)
Unemployment rate				−0.0242	−0.0242	−0.0242
				(0.006)	(0.005)	(0.005)
Constant	6.228	6.407	5.372	4.407	4.313	4.198
	(0.167)	(0.142)	(6.202)	(5.446)	(5.152)	(4.693)
p-value: $\beta_1 = \beta_2$	0.001	0.004	0.003	0.004	0.004	0.001
Instrument F-statistic					3.57	310.93
p-value					0.067	<0.001
Observations	42	42	42	42	42	42
R^2	0.72	0.73	0.73	0.76	0.76	0.76

Notes: The dependent variable is the log of gasoline consumption per capita. The real carbon tax-exclusive price of gasoline and the real carbon tax are measured in 2005 Swedish kronor. GDP per capita is measured in 2005 Swedish kronor (thousands). Urban population is measured as percentage of total population. Unemployment is measured as percentage of total labor force. Columns 5 and 6 use the real energy tax and the brent crude oil price as instrumental variables for the carbon tax-exclusive gasoline price. Newey-West standard errors are in parentheses; heteroscedasticity and autocorrelation robust. Standard errors are calculated using 16 lags, chosen with the Newey-West (1994) method.

Source: Data on GDP per capita and unemployment was obtained from Statistics Sweden (2015).

[Replicated Table 3]

	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	6.228	6.407	5.372	4.407	4.313	4.198
	(0.100)	(0.190)	(3.365)	(3.107)	(3.941)	(3.103)
real_carbontaxexclusive_with_vat	-0.057	-0.060	-0.061	-0.060	-0.062	-0.064
	(0.015)	(0.015)	(0.015)	(0.014)	(0.035)	(0.017)
real_carbontax_with_vat	-0.260	-0.232	-0.234	-0.186	-0.186	-0.186
	(0.032)	(0.044)	(0.045)	(0.045)	(0.045)	(0.045)
d_carbontax	0.109	0.060	0.063	0.100	0.098	0.095
	(0.038)	(0.065)	(0.066)	(0.058)	(0.078)	(0.062)
t	0.021	0.025	0.024	0.034	0.034	0.034
	(0.002)	(0.005)	(0.005)	(0.007)	(0.005)	(0.007)
real_gdp_cap_1000		-0.001	-0.001	-0.004	-0.004	-0.004
		(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
urban_pop			0.013	0.030	0.031	0.033
			(0.041)	(0.038)	(0.049)	(0.039)
unemploymentrate				-0.024	-0.024	-0.024
				(0.007)	(0.008)	(0.007)
Num.Obs.	42	42	42	42	42	42
R2	0.720	0.726	0.726	0.758	0.758	0.758
R2 Adj.	0.690	0.688	0.679	0.709	0.709	0.708
AIC	-97.1	-96.0	-94.1	-97.3	-97.3	-97.3
BIC	-86.7	-83.8	-80.2	-81.7	-81.7	-81.6
Log.Lik.	54.562	54.997	55.045	57.666		
F	27.865	23.303	25.409	28.978		
RMSE	0.07	0.07	0.07	0.06	0.06	0.06
Std.Errors	HC1	HC1	HC1	HC1	HC1	HC1

[Our Replication Code for Table 3]

```
install.packages("modelsummary")
library(haven)
library(modelsummary)
library(ivreg)

data_carbon <- read_dta("Downloads/data/disentangling_regression_data.dta")

model1 <- lm(log_gas_cons ~ real_carbontaxexclusive_with_vat +  real_carbontax_with_vat +
        d_carbontax + t, data =  data_carbon)
model2 <- lm(log_gas_cons ~ real_carbontaxexclusive_with_vat +  real_carbontax_with_vat +
        d_carbontax + t + real_gdp_cap_1000,  data = data_carbon)
model3 <- lm(log_gas_cons ~ real_carbontaxexclusive_with_vat +  real_carbontax_with_vat +
        d_carbontax + t + real_gdp_cap_1000 + urban_pop, data = data_carbon)
model4 <- lm(log_gas_cons ~ real_carbontaxexclusive_with_vat + real_carbontax_with_vat +
        d_carbontax + t + real_gdp_cap_1000 + urban_pop + unemploymentrate, data =
        data_carbon)

iv_model1 <- ivreg(log_gas_cons ~ real_carbontaxexclusive_with_vat +
        real_carbontax_with_vat + d_carbontax + t + real_gdp_cap_1000 + urban_pop +
        unemploymentrate | real_energytax_with_vat + real_carbontax_with_vat +
        d_carbontax + t + real_gdp_cap_1000 + urban_pop + unemploymentrate, data =
        data_carbon)
iv_model2 <- ivreg(log_gas_cons ~ real_carbontaxexclusive_with_vat +
        real_carbontax_with_vat + d_carbontax + t + real_gdp_cap_1000 + urban_pop +
        unemploymentrate | real_oil_price_sek + real_carbontax_with_vat + d_carbontax
        + t + real_gdp_cap_1000 + urban_pop + unemploymentrate, data = data_carbon)

modelsummary(list(model1, model2, model3, model4, iv_model1, iv_model2), vcov = "stata")
```

Works Cited

Andersson, Julius J. 2019. “Carbon Taxes and CO2 Emissions: Sweden as a Case Study.” American Economic Journal: Economic Policy 11 (4): 1–30. https://doi.org/10.1257/pol.20170144.

“What Is Carbon Leakage?” 2020. CLEAR Center. April 24, 2020. https://clear.ucdavis.edu/news/what-carbon-leakage.