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Cars, carbon taxes and CO2 emissions

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Cars, Carbon Taxes and CO_2 Emissions

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Abstract: Is a carbon tax effective in reducing emissions of greenhouse gases, and thereby mitigating climate change? I estimate the reduction in emissions of carbon dioxide (CO_2) from the transport sector in Sweden during the years 1990 to 2005 as a result of the introduction of a carbon tax and a value added tax (VAT) on transport fuel in the years 1990-1991. To capture the causal effect on emissions I construct a synthetic Sweden, the counterfactual Sweden that does not receive the 'treatment' in 1990-1991, using the synthetic control method. The results show an average annual reduction in emissions of 10.9%, or 2.5 million metric tons of CO_2, during the post-treatment period of 1990-2005. Looking at the effect of the carbon tax in isolation I estimate an average annual post-treatment reduction of 4.9%, or 1.1 million metric tons of CO_2. The results are robust to a series of placebo tests, both in-time and in-space. Taken together, my findings show that a carbon tax can be an efficient tool to mitigate climate change.

JEL-classification: Q58, H23

Keywords: Carbon tax, transport sector, synthetic control method, climate change

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1. Introduction

In this paper I provide an estimate of the reduction in emissions of carbon dioxide (CO_2) from 1990 to 2005 in the Swedish transport sector as a result of the introduction of a carbon tax and a value added tax (VAT) on transport fuel in the years 1990-1991. I first construct synthetic Sweden, the counterfactual Sweden that does not receive the 'treatment' (i.e., the carbon tax and VAT), using the synthetic control method (Abadie and Gardeazabal 2003; Abadie, Diamond, and Hainmueller 2010; 2014). Secondly, I estimate the difference in emissions between Sweden and synthetic Sweden and analyse how robust the results are by performing a series of placebo tests. Lastly, I try to disentangle the effect of the carbon tax and the VAT from each other. My results show that the policy changes of introducing a carbon tax and VAT in 1990-1991 had a significant effect on CO_2 emissions from the transport sector.

In 1991 Sweden was one of the first countries in the world to introduce a carbon tax. The tax level was initially set at 250 SEK ($30) per ton of CO_2 and then successively raised to the current level of 1100 SEK ($132). The goal of the tax is to reduce emissions of CO_2, the main greenhouse gas (GHG) contributing to climate change, by equalizing the private and social cost of carbon. In the year prior, in March of 1990, Sweden also added VAT of 25% to the price of gasoline and diesel. The VAT is applied to both the underlying cost of the transport fuel and any added energy and/or carbon taxes.

Although the carbon tax was implemented quite broadly, some sectors of the economy, especially industry and agriculture received a lower rate in 1993 and onwards due to competitive concerns, and some high-energy sectors, such as mining and the pulp and paper industry, are fully exempted from paying the tax. Consequently, when evaluating the environmental efficiency of the tax it is not advisable to look at *total* CO_2 emissions in Sweden since many units in the economy do not receive the treatment.[1] Fortunately, the transport sector, the largest source of CO_2 emissions in Sweden, is fully covered by the carbon tax and thus a suitable sector to analyse. From 1990 to 2005 the sector was responsible for close to 40% of Sweden's annual CO_2 emissions.

An advantage of focusing solely on transport is that the risk of carbon leakage – firms reallocating to countries without strict climate change policies – is arguably smaller for this sector compared to, for instance, manufacturing and energy production. If a carbon tax in country X leads to carbon leakage and increase of emissions in country Z, we have interference between

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[1] Two underlying assumptions in analyses of causal effects are (1) no interference between units, and that (2) all treated units receive the same dose of the treatment. If total CO_2 emissions are the dependent variable in our analysis, then clearly assumption (2) is violated.

units. An analysis of country X would thus overestimate the effect on emissions from the carbon tax. Transportation of goods and people, however, still needs to be done within a country's borders and cannot easily be outsourced.

From 1990 to 2007, GHG emissions in Sweden decreased by 9% while GDP grew by 48% (Ministry of the Environment and Energy 2009). One may be tempted to put forward this as evidence that the carbon tax has been successful. The problem is that these emissions reductions cannot be taken as evidence of the causal effect of the tax since we have no counterfactual to compare with. This is the fundamental problem of causal inference: we cannot observe the outcome under treatment *and* the outcome when not treated, for the same unit (Holland 1986). To address this problem I make use of the synthetic control method, which allows me to create the missing counterfactual as a synthetic Sweden, consisting of a weighted combination of suitable 'donor' countries that did not implement carbon taxation, or other similar policy changes, but that had similar pre-treatment trajectories of CO_2 emissions in the transport sector.

This study is one of the few ex-post empirical studies that estimate the causal effect on emissions from carbon taxation. Sweden, together with Denmark, Finland, Norway and the Netherlands, were the first countries to implement carbon taxes, and did so in the early 1990s. However, almost all studies of the environmental impact of these taxes are ex-ante simulations and very few are ex-post empirical studies (Andersen et al. 2001; Baranzini & Carattini 2013). This lack of ex-post empirical studies is likely due to methodological difficulties, specifically the issue that "no base-line scenario without the tax exists for purposes of comparison" (Bohlin 1998, p. 283). This issue is precisely what the synthetic control method seeks to overcome. The few ex-post studies that do exist all find that carbon taxes have had either no impact (Lin & Li 2011; Bohlin 1998) or a fairly small impact on CO_2 emissions. For example, Brunvoll and Larsen (2004) find a 2% reduction in Norwegian CO_2 emissions as a result of that country's carbon tax. Contrary to these studies, I find transport CO_2 emissions in Sweden to be 12.5%, or 3.2 million metric tons, lower in 2005 than they would have otherwise been in the absence of the policy changes. The average annual reduction in emissions for the 1990-2005 period is 10.9%, or 2.5 million metric tons of CO_2. And from the carbon tax alone I estimate an average annual reduction of 4.9%.

2. Method and Data

To assess the carbon tax in Sweden, I first construct the missing counterfactual using a weighted combination of other OECD countries that resemble Sweden on a number of key predictors for

CO_2 emissions in transport prior to treatment. This particular method of constructing the counterfactual, called the synthetic control method, is developed and described in Abadie and Gardezabal (2003) and Abadie, Diamond, and Hainmueller (2010; 2014)[2].

Let $J+1$ be the number of OECD countries in my sample, indexed by j, and let $j=1$ denote Sweden, the "treated unit". The units in the sample are observed for time periods $t=1,2,\ldots,T$. It is important to have data on a sufficient amount of time periods prior to treatment $1,2,\ldots,T_0$ and post treatment $T_0+1,T_0+2,\ldots,T$ to be able to both construct a synthetic Sweden and evaluate the effect of the treatment.

Next we define two potential outcomes: Y_{jt}^I refers to CO_2 emissions from transport when exposed to treatment for unit j at time t and Y_{jt}^N is CO_2 emissions without treatment. The goal of the analysis is to measure the post-treatment effect on emissions in Sweden, which can be formalised as $\alpha_{1t}=Y_{1t}^I-Y_{1t}^N$. However, since we cannot observe Y_{1t}^N in the post-treatment period we need to construct it using synthetic control.

Synthetic Sweden is constructed as a weighted average of control countries $j=2,\ldots,J+1$ from my donor pool of OECD countries, and represented by a vector of weights $W=(w_2,\ldots,w_{J+1})'$ with $0\leq w_j\leq 1$ and $w_2+\cdots+w_{J+1}=1$. Each choice of Wgives a certain set of weights and hence characterises a possible synthetic control. We want the synthetic control to not only be able to reproduce the trajectory of CO_2 emissions but also to be similar to Sweden on a number of pre-treatment predictors of the outcome variable. Hence, let Z_j denote the vector of observed predictors for each unit in the sample. Now suppose that we find $W=W^*=(w_2^*,\ldots,w_{J+1}^*)$ such that for the pre-treatment period $t\leq T_0$ we have that

$$\sum_{j=2}^{J+1} w_j^* Y_{j1}=Y_{11}, \sum_{j=2}^{J+1} w_j^* Y_{j2}=Y_{12}, \cdots, \sum_{j=2}^{J+1} w_j^* Y_{jT_0}=Y_{1T_0}, \text{ and } \sum_{j=2}^{J+1} w_j^* Z_j=Z_1$$

then, as proved in Abadie et al. (2010), for the post-treatment period $T_0+1,T_0+2,\ldots,T$ we can use the following as an unbiased estimator of α_{1t}:

$$\hat{\alpha}_{1t}=Y_{1t}-\sum_{j=2}^{J+1} w_j^* Y_{jt}$$

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[2] The description here follows the structure in Abadie, Diamond, and Hainmueller (2010; 2011).

To find W^* we need to define a measurable distance between Sweden and its control units which we then minimize. Let $X_1 = (Z_1', Y_{11}, \dots, Y_{1T_0})'$ denote an $(k \text{ x } 1)$ vector of pre-treatment values for the key predictors of the outcome variable and the outcome variable itself for Sweden, and let the $(k \text{ x } J)$ matrix X_0 contain similar variables for the control countries.[3] We then choose W^* so that the distance $\|X_1 - X_0W\|$ is minimized for the pre-treatment period, subject to the above (convexity) constraints on the weights. In this paper I solve for a W^* that minimizes:

$$\|X_1 - X_0W\|v = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}$$

where V here is the $(k \text{ x } k)$ symmetric and positive semidefinite matrix that minimizes the mean squared prediction error (MSPE) of the outcome variable over the entire pre-treatment period.[4]

The purpose of introducing V is to weight the predictors and allow more weight being given to more important predictors of the outcome variable. Here, V is chosen through a data-driven procedure but other methods are possible, for instance, assigning weights to the predictors based on empirical findings in the literature on the main drivers of CO_2 emissions, or cross-validation methods (Abadie et al. 2014).

2.1 Data

I use annual panel data on CO_2 emissions from transport for the years 1960-2005 for 24 OECD countries (including Sweden). I chose 2005 as the end date because that year was the start of the EU Emissions Trading System (EU ETS), one of the main building blocks of the EU's climate change policy, and also because many countries in the sample implemented carbon taxes or made marked changes to fuel taxation from 2005 and onwards. The sample period hence gives me thirty years of pre-treatment data and sixteen years of post-treatment data, which should be enough to both construct a viable synthetic Sweden and enough time post-treatment to evaluate the effect of the policy changes.

From this initial sample of donor countries I exclude countries that during the sample period enacted carbon taxes that cover the transport sector, in this case: Finland, Norway, and the Netherlands, or made large changes to fuel taxes, which exclude Germany, Italy, and the

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[3] Note that the main analysis does not use all pre-treatment values for the outcome variable, only values for three distinct years.

[4] To find V (which here is diagonal) and W^* I used a statistical package for R called Synth (Abadie et al. 2011).

UK.[5] Additionally, I exclude Austria and Luxembourg due to “fuel tourism” skewing their emissions data. Austria’s emissions data is skewed from the year 1999 and onwards. This is due to Austria lowering fuel taxes in 1999, while neighbouring Germany and Italy increased their fuel taxes the same year. Austria is a major transit country and large trucks in particular tend to fill up in countries with low diesel prices on their way through Europe. In 2005, diesel sales in Austria where 150% higher than a decade earlier, a clear indication that “fuel tourism” had taken place. Luxembourg has had lower fuel taxes than neighbouring European countries for many years, which explains them having five to eight times higher per capita consumption of fuel than their neighbours (European Federation for Transport and Environment 2011) and more than two times higher CO_2 emissions from transport than the next highest emitter in the sample. Lastly, I exclude Ireland due to their unique “Celtic Tiger” economic expansion in the 1990s which more than doubled both their GDP per capita and CO_2 emissions per capita from transport during the post-treatment period. This rapid economic expansion is very dissimilar to Sweden’s and the other donor countries’ development during the same time period.[6] In the end, my donor pool consists of 14 countries: Australia, Belgium, Canada, Denmark, France, Greece, Iceland, Japan, New Zealand, Poland, Portugal, Spain, Switzerland, and the United States.

The outcome variable is per capita CO_2 emissions from transport and measured in metric tons. The data, obtained from the World Bank, contains emissions from the combustion of fuel from road, rail, domestic navigation, and domestic aviation, excluding international aviation and international marine bunkers. As key predictors I use GDP per capita, number of motor vehicles (per 1000 people), gasoline consumption per capita, and percentage of urban population (see Appendix for details and sources). The level of GDP per capita is shown in the literature to be closely linked to emissions of greenhouse gases (Neumayer, 2004), and OECD countries that are less urbanized have a higher usage of motor vehicles and hence higher emissions from transport. I average the four key predictors over the 1980-1989 period. Finally, to the list of predictors I add three lagged years of CO_2 emissions: 1970, 1980, and 1989.

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[5] Denmark also implemented a carbon tax, in 1992. However, their tax level is set very low and, more importantly, the transport sector is exempted.

[6] Note that including Austria and Ireland in the donor pool does not change the main results in this paper since they both receive zero weights in synthetic Sweden.

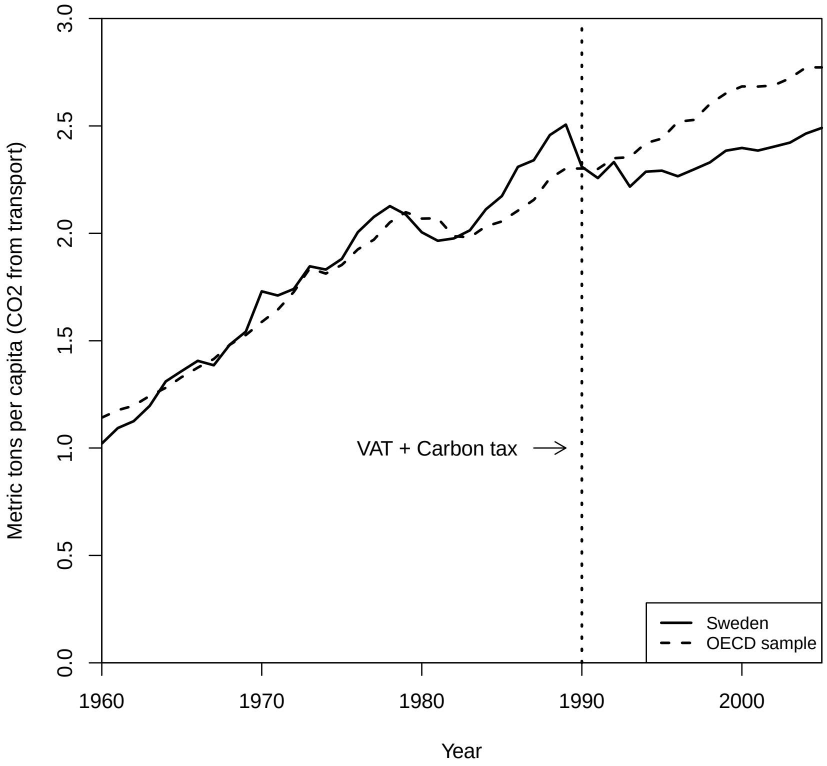

Figure 1. Trajectory of CO_2 emissions from transport in Sweden vs. the OECD average of my 14 donor countries.

Figure 1 shows the trajectory of emissions from transport in Sweden and the OECD average during the sample period[7]. The fit is particularly poor for the ten years prior to the introduction of the carbon tax and VAT. Next, in the results section, I show how the synthetic control method is able to provide a synthetic Sweden with a much better fit on emissions for the pre-treatment period. This thus gives us a more reliable way to estimate the causal effect on emissions as a result of the policy changes.

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[7] The slump in emissions in Sweden and the OECD countries in the years following 1979 is a response to what is commonly called the "second oil crisis", prompted by the Iranian Revolution in 1979. It wasn't until around 1986 that the price of oil was back down at pre-1979 levels. This increase in the oil price hence acts as a 'natural experiment' that shows that increased prices of fuel leads to reductions in CO_2 emissions from transport.

3. Results and Robustness Check

First, I analyse if synthetic Sweden is able to track the CO_2 emissions from transport in Sweden for the pre-treatment period and how closely it reproduces the values of the key predictors. A good fit is important to lend credibility to our identification assumption, which asserts that synthetic Sweden shows the trajectory of CO_2 emissions from transport in Sweden from 1990 to 2005 had the policy changes of introducing VAT and a carbon tax not taken place.

Figure 2 shows that, prior to treatment, CO_2 emissions from transport in synthetic Sweden track actual emissions in Sweden very closely. The average (absolute) difference for the pre-treatment period is only around 0.03 metric tons of CO_2 (or 1.79%).

Table 1 compares the values of the key predictors for Sweden prior to 1990 with the same values for synthetic Sweden and a population-weighted average of the 14 OECD countries in the donor pool. For all predictors except gasoline consumption per capita, Sweden and synthetic Sweden have very similar values and a much better fit compared to the OECD average. It is especially encouraging to see the good fit on GDP per capita.

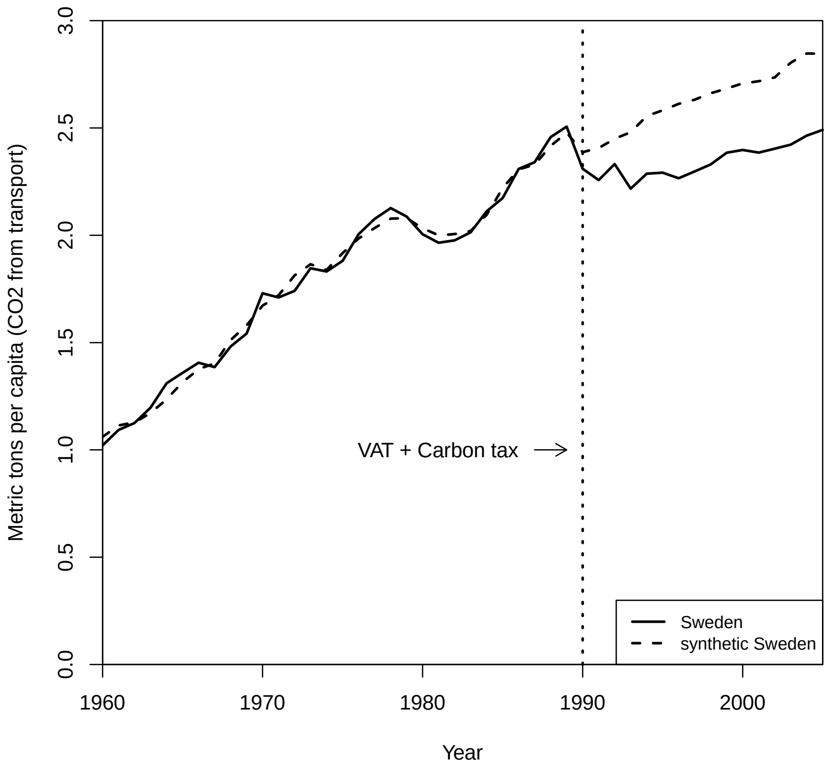

Figure 2. Path plot of per capita CO_2 emissions from transport during 1960-2005: Sweden vs. synthetic Sweden.

Table 1. Predictor means for CO_2 emissions from transport

Variables	Sweden	Synthetic Sweden	OECD Sample
GDP per capita	20121.48	20121.21	21277.78
Motor vehicles (per 1000 people)	405.56	406.22	517.48
Gasoline consumption per capita	456.18	406.77	678.91
Urban population (%)	83.10	83.08	74.05
CO_2 from transport per capita 1989	2.51	2.48	3.49
CO_2 from transport per capita 1980	2.01	2.03	3.22
CO_2 from transport per capita 1970	1.73	1.67	2.77

Note: All variables except lagged CO_2 are averaged for the period 1980-1989. GDP per capita is Purchasing Power Parity (PPP)-adjusted and measured in 2005 U.S. dollars. Gasoline consumption is measured in kg of oil equivalent. CO_2 emissions are measured in metric tons. The values for the OECD sample are population-weighted averages.

In constructing synthetic Sweden, and choosing the V and W matrices, the MSPE of CO_2 emissions from transport is minimized over the entire pre-treatment period 1960-1989. This procedure gives the following V weights: GDP per capita (0.219); Motor vehicles (0.078); Gasoline consumption (0.010); Urban population (0.213); CO_2 emissions from transport in 1989 (0.183); 1980 (0.284); and, 1970 (0.013). The low weight assigned to gasoline consumption per capita may explain the poor fit between Sweden and synthetic Sweden on this variable.

Table 2. Country weights in synthetic Sweden

Country	Weight	Country	Weight
Australia	0.001	Japan	0
Belgium	0.195	New Zealand	0.177
Canada	0	Poland	0.001
Denmark	0.384	Portugal	0
France	0	Spain	0
Greece	0.090	Switzerland	0.061
Iceland	0.001	United States	0.088

Note: With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq w_j \leq 1$ and $\sum w_j = 1$.

The W weights reported in Table 2 shows that CO_2 emissions from transport in Sweden is best reproduced by a combination of Denmark, Belgium, New Zealand, Greece, the United States, and Switzerland. The rest of the countries in the donor pool get either a weight of zero, or very close to zero. The large weight given to Denmark (0.384) seems reasonable considering that Sweden and Denmark are similar in many social and economic dimensions.

3.1 Emission Reductions

The post-treatment distance between Sweden and synthetic Sweden in Figure 2 measures the reduction in CO_2 emissions. This distance is further visualised in the gap plot of Figure 3. The introduction of the VAT and the gradual increase of the carbon tax create larger and larger reductions during the post-treatment period. In the last year of the sample period, 2005, emissions from transport in Sweden are 12.5%, or -0.35 metric tons per capita, lower than they would have been in the absence of treatment. The average annual reduction in emissions for the 1990-2005 period is 10.9%, or -0.29 metric tons of CO_2 per capita. Aggregating over the total population gives an emission reduction of 3.2 million tonnes of CO_2 in 2005 and an annual average for the 1990-2005 period of 2.5 million tonnes of CO_2. The total cumulative reduction in emissions for the post-treatment period is 40.5 million tonnes of CO_2.

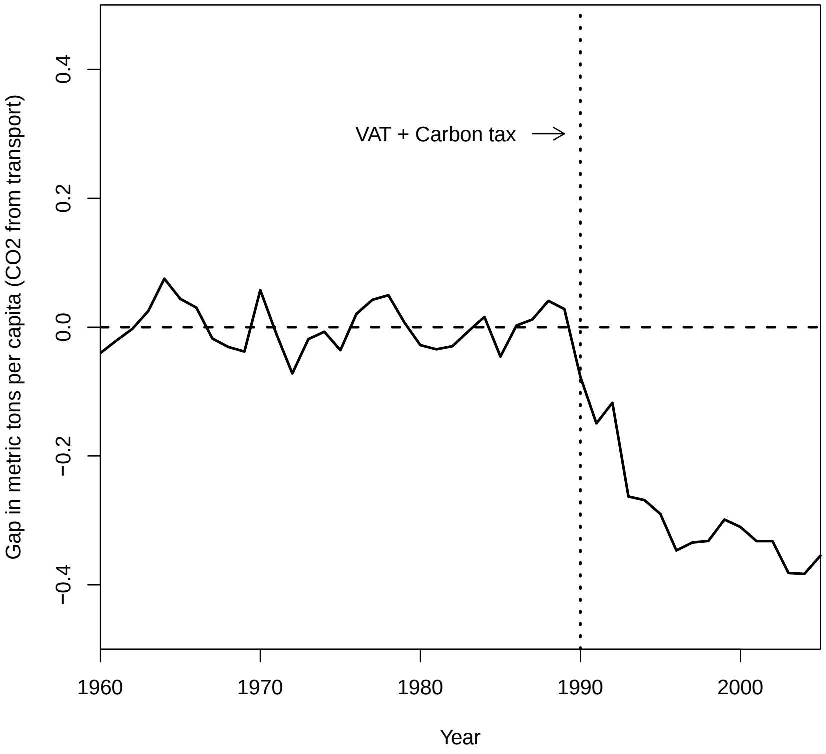

Figure 3. Gap in per capita CO_2 emissions from transport between Sweden and synthetic Sweden.

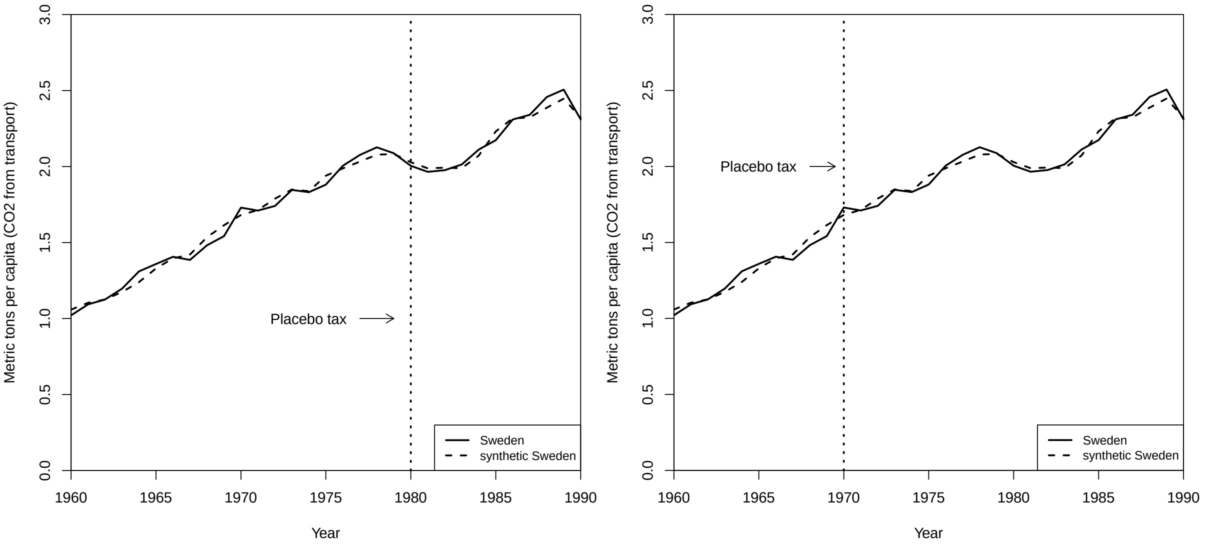

Figure 4. Placebo in-time tests: In the left figure the placebo tax is introduced in 1980, ten years prior to the actual policy changes. In the right figure the placebo tax is introduced in 1970.

3.2 Placebo Tests

To further test the validity of the results I performed a series of placebo tests, both in-time and in-space. For the in-time tests the year of treatment is shifted to 1980 and 1970, years that are both prior to the actual policy changes. We want to find that this placebo treatment does not result in a post-treatment divergence in the trajectory of emissions between Sweden and synthetic Sweden. A large placebo effect casts doubt on the claim that the results illustrated in Figure 2 and 3 is the actual causal effect of the carbon tax and the VAT.

Figure 4 shows that for both in-time placebo tests the post-placebo-treatment trajectory for Sweden and synthetic Sweden are very similar. Hence, these placebo tests lend confidence to the claim that the results from the main analysis are indicative of the actual reduction in emissions.

For the in-space placebo tests the treatment is reassigned to all countries in the donor pool, again using the synthetic control method to construct synthetic counterparts. This gives us a method to establish if the result obtained for Sweden is unusually large, by comparing that result with the placebo results for all the countries in the donor pool. This form of permutation test allows for inference and the calculation of p-values: measuring the fraction of countries with results larger than or as large as the one obtained for the treated unit (Abadie et al. 2014, p. 6).

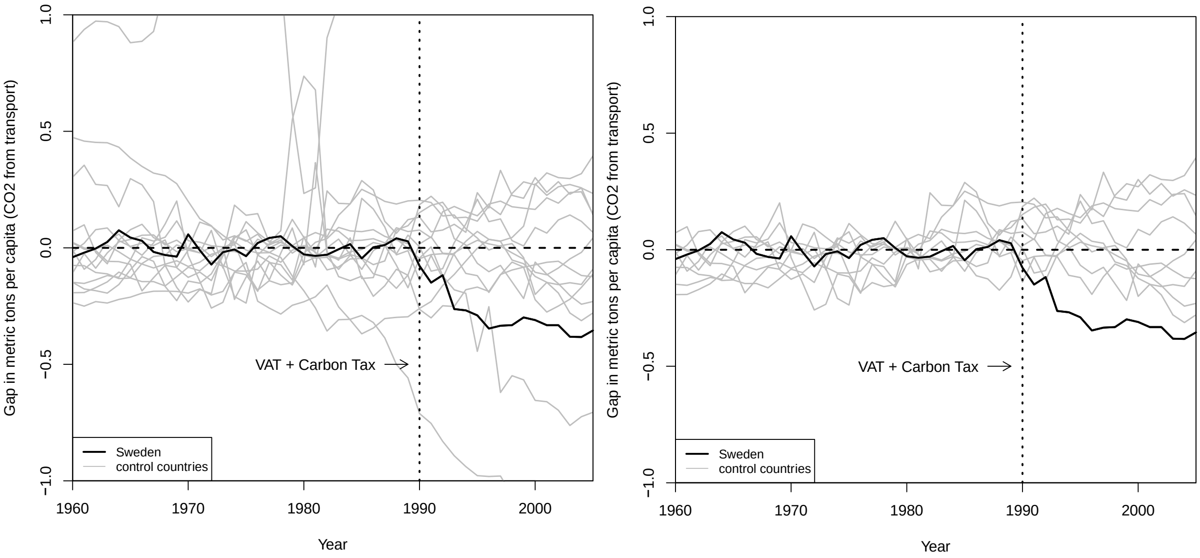

Figure 5. Permutation test: Per capita CO_2 emissions gap in Sweden and placebo gaps for the control countries.

Figure 5 shows the results of the in-space placebo tests. The plot on the left indicates that for some countries in the donor pool, the synthetic control method is not able to find a convex combination of countries that can simulate the path of emissions in the pre-treatment period. This is especially true for the United States, Poland and Portugal. This is not surprising since the United States has the largest CO_2 emissions during all the pre-treatment years and Poland and Portugal have the lowest. Therefore, in the plot on the right, all the countries in the donor pool with a pre-treatment MSPE at least twenty times larger than Sweden's is excluded, which leave nine countries in the donor pool. Now the gap in emissions for Sweden in the post-treatment period is the largest of all remaining countries. The p-value of estimating a gap of this magnitude is thus $1/10 = 0.10$.

However, the choice of a particular cut-off threshold for the MSPE value when doing permutation testing is arbitrary. A better inferential technique is to look at the ratio of post-treatment MSPE to pre-treatment MSPE (Abadie et al. 2010), with the assumption that a large ratio is indicative of a true casual effect from treatment. With the ratio test we do not have to discard any of the countries in the donor pool based on an arbitrarily chosen cut-off rule, and thus the ratio test is advantageous when you have a small number of control units.

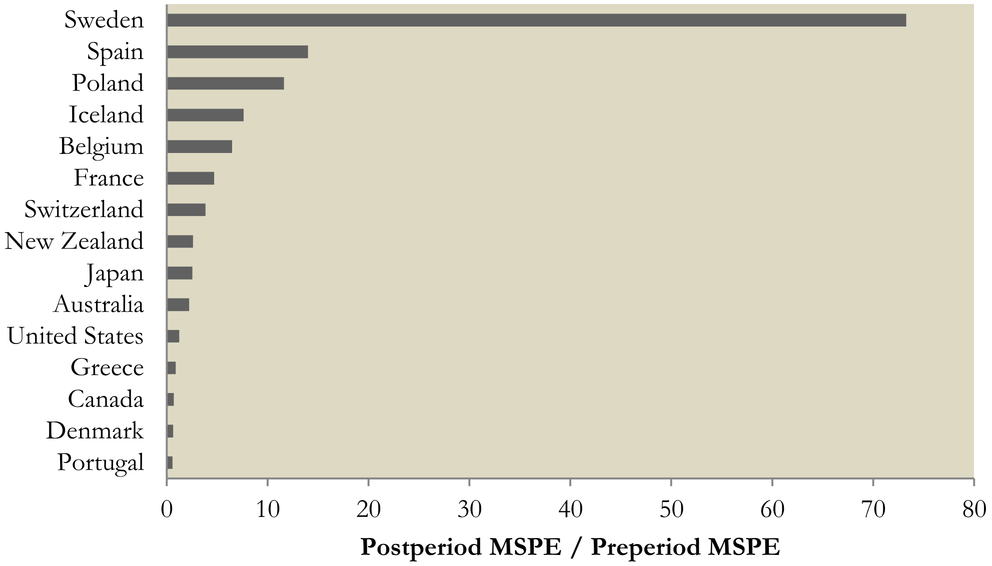

Figure 6. Ratio test: Ratios of post-treatment MSPE to pre-treatment MSPE.

The ratio test in Figure 6 shows that Sweden by far has the largest ratio of all the countries in the sample. If one was to assign the treatment at random, the probability of finding a ratio as large as the one for Sweden is 1/15 = 0.067, the smallest possible p-value with my sample size.

4. Disentangling the effect of the carbon tax

Although the VAT and the carbon tax were introduced just a few months apart, it is of interest from an environmental economics perspective to disentangle and isolate the effect of the carbon tax on emissions. This way we can evaluate the environmental efficiency of carbon taxation and compare the results with other countries that similarly have implemented carbon taxes.

Emissions of CO_2 from the transport sector consist 90-95% of emissions from road transport (Ministry of the Environment and Energy 2009). And in turn, emissions from road transport are linked to gasoline and diesel consumption. Figure 7 shows the trend in per capita consumption of gasoline and diesel in Sweden during 1960 to 2005. It is clear from this figure that there is a change of trend in the post-treatment period. There are three things to note here. First, due to the increase in fuel prices in 1990-1991 there has been a substitution away from passenger cars run on gasoline to passenger cars run on diesel, since the fuel efficiency of diesel vehicles typically is significantly higher (Sterner 2006, p. 26). In 1990, 2.9% of all passenger cars were run on diesel, whereas this percentage increased to 5.2% in 2005 (Eurostat 2015).

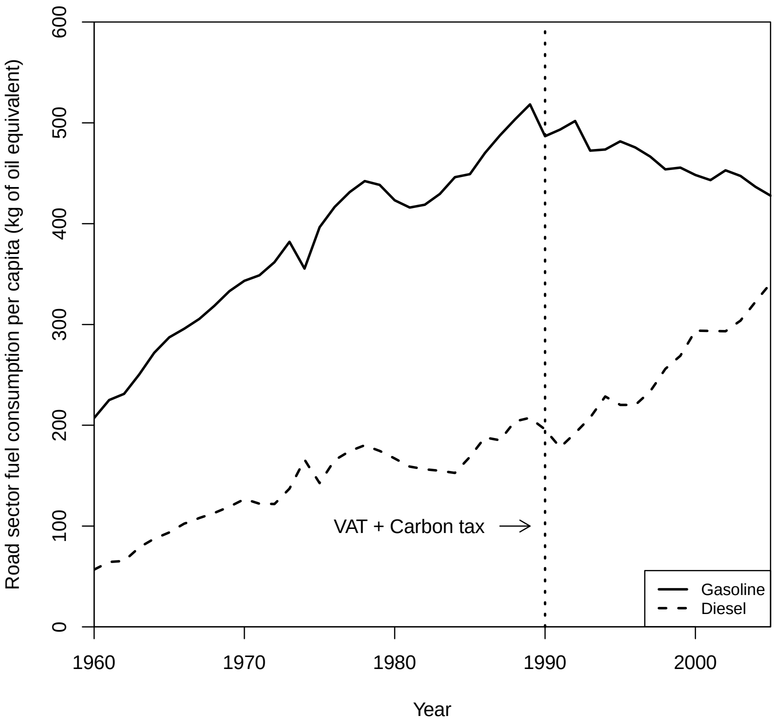

Figure 7. Road fuel consumption per capita in Sweden during 1960-2005.

Secondly, between 1990 to 2005 the amount of lorries, semi-trailers, trailers, and tractors, which all typically run on diesel, increased by 47%. This large increase is likely linked to amplified shipment of goods due to globalisation, and Sweden intensifying its trade with the rest of Europe after joining the EU in 1995. Lastly, companies which are the main users of lorries, trailers and tractors have the VAT on fuel refunded back to them. Hence, they are only impacted by the carbon tax and we should thus see smaller changes in their fuel consumption compared to regular gasoline consumers, especially since the demand elasticity for diesel in Sweden is estimated to be as low as -0.25 (Dahl 2012). Taken together, this explains why we see a large change of trend in gasoline consumption in the post-treatment period but not a similar change in diesel consumption.

4.1 Emission reductions due to the carbon tax

Since gasoline constitute the largest part of fuel consumption, my estimate of the emission reductions attributable to the carbon tax uses data only for the relationship between the VAT rate and the carbon tax rate on gasoline. Note though that this estimate serves as a lower bound since the emission reductions attributable to changes in diesel consumption are mainly due to the carbon tax since the VAT only affects a small percentage of the consumers of diesel.

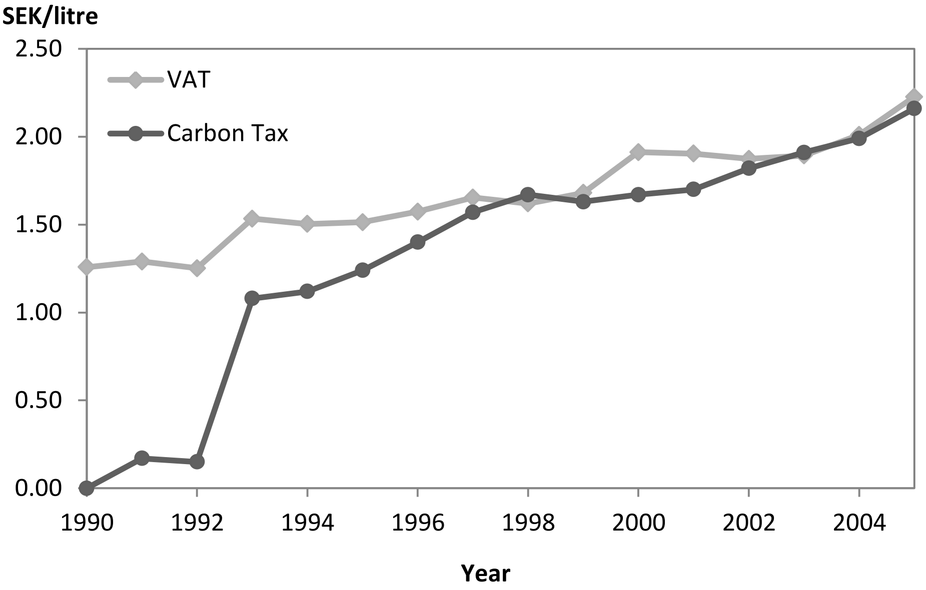

Figure 8. The VAT and carbon tax component of the price of gasoline in Sweden.

Since the introduction of the carbon tax there have been minor alterations in the rate of the existing energy tax that is added to gasoline. The energy tax was increased slightly during 1992-2000 and then reduced between 2000 and 2005, while the carbon tax has been increased over the post-treatment period. When measuring the carbon tax level in figure 8 I fixed the energy tax at the rate applied in 1990. In 2005 the carbon tax was 910 SEK ($109) per ton of CO_2 and the calculations made in this section assume a carbon tax of 930 SEK ($111) per ton of CO_2, hence this small difference should not affect the results much.

Adding the carbon tax and the VAT together we get an average combined tax rate for the 1990-2005 period of 1290 SEK ($155) per ton of CO2 and 1887 SEK ($226) per ton of CO_2 in 2005. Compared to the actual carbon tax rate in 2014, the average combined tax rate is 17% higher and the 2005 combined rate is 72% higher.

In 2005 the carbon tax comprised close to 50% of the combined rate of the carbon tax and the VAT. Making a rough assumption that this percentage translates into reductions in CO_2 emissions associated to the carbon tax gives a reduction in 2005 of 6.2%, or -0.17 metric tons of CO_2 per capita. Over the entire post-treatment period the carbon tax has comprised 40% of the combined tax rate and led to average annual emission reductions of 4.9%, or -0.13 metric tons of CO_2 per capita. Aggregating over the total population gives an emission reduction, attributable to the carbon tax, of 1.6 million metric tons of CO_2 in 2005 and an annual average for the 1990-2005 period of 1.1 million metric tons of CO_2.

4.2 Estimates from previous literature

My estimated emission reductions can be compared to previous estimates from analyses of the Swedish carbon tax. However, most analyses are ex-ante modelling studies and very few are ex-post empirical studies, and even fewer look at the transport sector in isolation.

In Bohlin (1998) the author concludes that during 1990-1995 the carbon tax had no impact on emissions from the transport sector. I instead find an average annual emission reduction of 2.6% during 1990-1995 attributed to the carbon tax with a reduction in 1995 alone of 5%.

Sweden's fifth national report on climate change (Ministry of the Environment and Energy 2009) estimates that the reduction of CO_2 emissions from the transport sector in 2005 is 1.7 million metric tons compared to if Sweden had kept taxes at the 1990 level. The emissions reduction is modelled by estimating changes in fuel consumption, using price elasticities of demand for fuel. However, the report does not clearly specify if the effect of the introduction of VAT in 1990 is included or not in their estimates, making it harder to compare their results with mine. If VAT is included, then their estimate is markedly lower compared to my estimate of emissions reduction in 2005 of 3.2 million metric tons of CO_2. If the VAT is not included, which is more likely, their estimate of a reduction of 1.7 million metric tons is close to my estimate of 1.6 million metric tons (from the carbon tax alone), but their methodology is then flawed since they do not take into account the long-term effect on emissions from the introduction of the VAT just a few months prior to the start date of their calculations.

5. Conclusion

In the environmental economics literature on climate change there is much emphasis on carbon taxation as an environmentally and economically efficient way to reduce greenhouse gases. However, there are very few real world examples of countries implementing carbon taxes and even fewer ex-post studies that capture the causal effect on emissions from these taxes.

In this paper I have estimated the reduction in CO_2 emissions from the transport sector in Sweden following the introduction of a carbon tax and VAT in the years 1990-1991. With the use of the synthetic control method I estimate the causal effect to be an average annual reduction in emissions of 10.9%, or 2.5 million metric tons of CO_2, during the post-treatment period of 1990-2005. Looking at the effect of the carbon tax in isolation I estimate an average annual post-treatment reduction of 4.9%, or 1.1 million metric tons of CO_2.

Synthetic Sweden is able to very accurately reproduce the values for Sweden on a number of key predictors of CO_2 emissions from the transport sector, and to closely track emissions during the thirty years prior to treatment. The results are furthermore robust to a series of placebo tests, both in-time and in-space. Reassigning the treatment at random in the sample shows that the probability of obtaining a post-treatment result as large as that for Sweden is just 0.067. Combined, the results of the analysis and the robustness tests lend weight to the claim that the estimated emission reductions capture the causal effect of the policy changes in Sweden.

Appendix: Data Sources

- CO_2 emissions from transport. Measured in metric tons per capita. Source: the World Bank WDI Database. Available at: data.worldbank.org/indicator.
- GDP per capita (PPP, 2005 USD). Expenditure-side real GDP at chained PPPs, divided by population. Source: Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2013), "The Next Generation of the Penn World Table". Available at: www.ggdc.net/pwt.
- Motor Vehicles (per 1000 people). Source: Dargay, Joyce, Dermot Gately and Martin Sommer (2007), "Vehicle Ownership and Income Growth, Worldwide: 1960-2030".
- Gasoline consumption per capita. Measured in kg of oil equivalent. Source: the World Bank WDI Database. Available at: data.worldbank.org/indicator.
- Urban Population. Measured in percentage of total. Source: the World Bank WDI Database. Available at: data.worldbank.org/indicator.

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