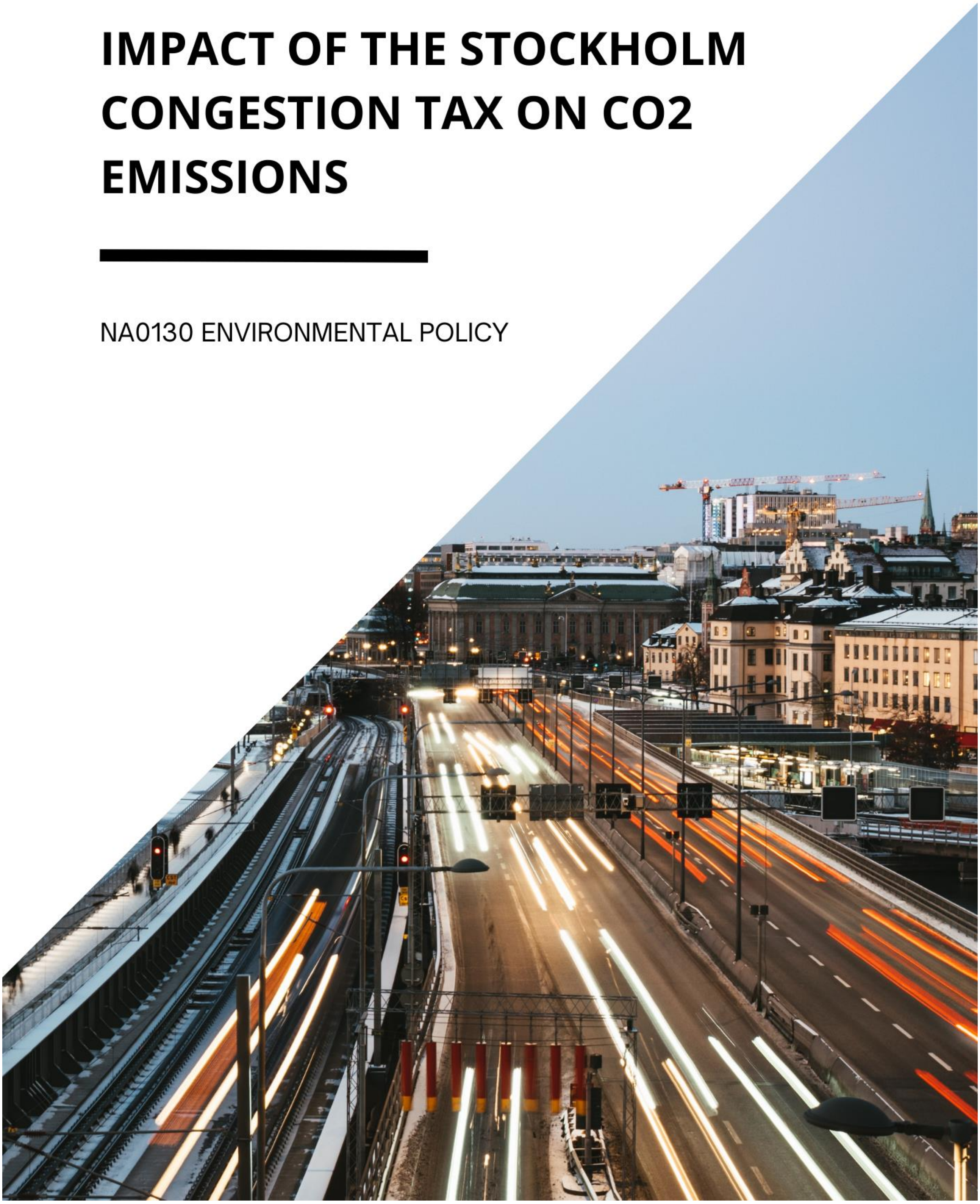
MAX ENGSTRÖM

IMPACT OF THE STOCKHOLM CONGESTION TAX ON CO2 EMISSIONS

NA0130 ENVIRONMENTAL POLICY



1 Introduction

Anthropogenic greenhouse gas (GHG) emissions are one of the main drivers of climate change (Ritchie and Roser, 2020). According to the Intergovernmental Panel on Climate Change (IPCC), without urgent and radical action to reduce GHG emissions by 2030, "global warming will exceed 1.5°C in the following decades, leading to irreversible loss of the most fragile ecosystems and successive crises for the most vulnerable people and societies" (IPCC, 2018). Of these greenhouse gases, carbon dioxide (CO2) has shown a significant increase of about 50% in 2021 compared to pre-industrial revolution levels (Gosden and Webster, 2021). In Sweden, road transport is one of the largest contributors to CO2 emissions, accounting for 30% of CO2 emissions in 2017 (Mellquist, et al., 2017), and 38% in 2020 (SCB, 2022 - 1 and 2).

The introduction of a carbon tax or Pigouvian tax can be an effective tool to reduce CO2 emissions by internalizing negative externalities. To target road traffic more precisely, an anti-congestion tax or toll can be introduced. This is what has been done in Stockholm under the name *trängselskatt*, from January 3 to July 31, 2006, for a trial period, and then from August 2007 until today. Charging vehicles entering and leaving the city center at certain stations, the primary objective of this pricing system is to reduce traffic jams, increase accessibility to the city and improve the environment by reducing air pollution and CO2 emissions (Stockholmsförsöket). The latter is achieved in two ways: on the one hand, the disincentive to use a car should lead directly to a reduction in emissions, and on the other hand, the reduction in the number of traffic jams leads in turn to a reduction in pollution (Stockholmsförsöket). The toll rate has been set to achieve the goal of reducing car traffic in Stockholm by 10-15% (Eliasson, 2014). While this tax is not in itself a carbon tax, it does aim to internalize negative externalities, including those with an environmental impact (CO2 emissions), and therefore seems relevant for this analysis.

The purpose of this study is to look at the effect of the congestion tax on the environment through its impact on CO2 emissions in the Stockholm area. It thus aims to answer the following question:

- What are the effects of the congestion tax implemented in Stockholm from 2006 on CO_2 emissions in the city and its region?

In order to answer this question, this paper relies on data from 2000 to 2012 on emissions per capita and various variables that relate to traffic, the economy, and the population. For Sweden, the data on these variables are taken from the Swedish Meteorological Hydrological Institute (SMHI) and Statistiska Centralbyrån (SCB). Data on other cities outside of Sweden would ideally be found at agencies in their respective countries.

The paper further aims at answering the question by conducting a synthetic control method, with the donor pool consisting of a number of European cities that have not been subjected to a similar congestion tax during the sample period. The outcome variable, that is per capita emissions, has been chosen as a measure of the effect on the environment. The other variables have been chosen for the purpose of constructing a reliable synthetic control unit that shares similar characteristics as Stockholm for the pre-treatment period.

Most of the previous studies that have been conducted on this topic have used cost-benefit analyses, while this study instead uses an empirical approach and might thus say something regarding causality. The contribution of this paper to existing literature would be in terms of the causal effect of the Stockholm congestion tax that very few studies have attempted before. Additionally, it would likely be the very first study that employs the synthetic control method on the Stockholm tax.

The paper is organized as follows: Section 2 provides a literature review of previous research studying similar taxes in different cities as well as for Stockholm, section 3 presents background information regarding the Stockholm congestion fee and the economic theory behind it, section 4 summarizes the data and its key variables used in this study, and section 5 presents the method.

2 Previous literature

Carbon taxes and their effects on GHGs and CO_2 emissions have been widely studied in the academic literature. Also referred to as Pigouvian taxes, they aim to reintegrate into market prices the social cost of externalities (in our case, environmental) caused by the various activities taxed (Nordhaus, 2014; Pigou and Aslanbeigui, 2017). Congestion charges have been widely studied for their impact on traffic in various cities such as London since 2003, Singapore since 1975, and Milan since 2012 (Phang and Toh in 1997 for Singapore; Santos and Shaffer in 2004 for London; Gibson and Carnovale in 2015 for Milan). A decrease in road traffic and travel time is evident regardless of the model used in most studies. The results seem however more nuanced concerning the effects of these taxes on the environment.

Using a spatially disaggregated model, Percoco (2015) shows that the London Congestion Charge leads to a decrease in the concentration of NO, NO2, and NO_X in the area subject to the tax and an increase in the surrounding areas, which he explains by the increase in the number of kilometers traveled due to the induced diversion. According to Green et al (2020), while a decrease in the main pollutants can be observed, the concentration of harmful NO2 has tended to increase. This is mainly due to the exemptions of diesel vehicles and the substitution phenomenon. This nuanced effect on pollution and GHG emissions is also confirmed in the case of Milan, where, in the first days after its introduction, the tax reduced the concentration of carbon monoxide and particulate matter. The effect was particularly only lasting in the short term because of the exemption of motorbikes (Percoco, 2013).

The literature that instead focuses on the Stockholm congestion tax implemented since 2006 is relatively rich, but it focuses mainly on cost-benefit analyses (Eliasson, 2009; Eliasson, 2014; Börjesson et al., 2012; Börjesson and Kristoffersson, 2017). It thus leaves the field open for an estimation of its effect on CO_2 emissions. First, using a time series model that controls for external factors (employment, fuel prices) and allows for long-term effects (population growth, inflation), Börjesson et al. (2012) show substantial effects of congestion pricing. The effects include reduced traffic, congestion, and travel time variability, improved air quality and reduced GHG emissions in both the trial and final implementation periods. They also show that during the interim period (August 2006 to August 2007), traffic immediately rebounded and was at levels of 5-10% lower than in 2005. Finally, they point to the price elasticity of traffic across the cordon being higher in the long run compared to the short run.

Also studying the price elasticity, Börjesson and Kristoffersson (2017) find that it is lower with subsequent extensions and increases of the tax than when the system was first introduced. These authors moreover compare the long-term trends of congestion charges introduced in 2006 in Stockholm and in 2013 in Gothenburg, while introducing the effects of the toll on different types of vehicles, including company cars (Börjesson and Kristoffersson, 2017).

These results of Börjesson and Kristoffersson (2017) are in line with those of Eliasson (2014), who finds that traffic decreased by 16% in the city center and by 5% on the access roads. The reduction was, according to him, greatest in the afternoon peak period (-23%), and somewhat smaller in the morning (-18%). However, he introduces an important fact in his analysis: the tax is accompanied by an extension of the already well-developed and efficient public transport services in Stockholm. Furthermore, he shows that the reduction in traffic has led to a reduction in GHG emissions of 10-15% in the city center and carbon dioxide emissions of 2-3% in the Stockholm region as a whole (Eliasson, 2014).

Simeonova et al. (2021) study the trial, in-between and final implementation periods of the tax on emissions. Using a difference-in-differences model that includes region-specific time trends and interactions with weather conditions, their study is one of the few that uses an empirical approach to look at the effects of the Stockholm tax. They conclude that anti-congestion pricing impacts human health and well-being through a 5-10% reduction in air pollution. Additionally, this affects children's breathing and leads to a reduction in acute asthma attacks among them. While these effects are positive in the short term, they are even stronger in the long term. All these factors help to explain the favorable development of public and political acceptability of the project (Eliasson, 2014; Börjesson et al., 2012; Börjesson and Kristoffersson, 2017; Börjesson, 2018).

Lastly, a Bachelor's thesis written by Thorell & Lamers (2019) estimates how the Stockholm Congestion Tax affects CO2 emissions and car traffic in the city. It uses a difference-in-differences method and finds that the congestion tax has had a negative effect on carbon dioxide emissions, even though the authors cannot conclude whether it is a causal effect or not.

From the literature, it can be concluded that the vast majority of studies that explore the impact of Stockholm's congestion toll on CO2 emissions are mainly based on predictive models and not empirical analysis. The study of Lamers and Thorell (2019) along with Simeonova et al. (2021) are the only studies found that use empirical approaches to measure the effects of the tax. It is this gap in the literature that this paper aims to address. Moreover, this paper seeks to complement previous empirical papers by using a synthetic control method.

3 Background

The Stockholm congestion toll:

The *trängselskatt* instrument forms a cordon around the city centre, covering an area of 35 km^2, with originally 18 toll points at the entry and exit of the city. It is a system of price differentiation over time (Figure 1) and that also introduces exemptions at its inception. Thus, until 2012, buses, foreign cars, and vehicles from Lidingö were not subject to this tax, as were alternative fuel vehicles until 2009 (Eliasson, 2014). From 2006 to 2016, the congestion tax was implemented from 06.30 to 18.29, with the maximum charge being from 07.30-08.29 and 16.00-17.29, and amounted to SEK 20. The maximum daily payment was SEK 60 (Trafikverket, 2016). In 2016, this tool was extended to cover the Essinge ring road and the price was increased (Börjesson and Kristoffersson, 2017). This is however not relevant to this study as the years considered in the analysis are 2000-2012.

6:30-7:00	10 SEK
7:00-7:30	15 SEK
7:30-8:30	20 SEK
8:30-9:00	15 SEK
9:00-15:30	10 SEK
15:30-16:00	15 SEK
16:00-17:30	20 SEK
17:30-18:00	15 SEK
18:00-18:30	10 SEK

Figure 1: The implementation of anti-congestion pricing in Stockholm. Left: Taxed area (dotted line), crossing points (red), untaxed ring road (solid line). Right: time-of-day rates (excluding weekends) (source: Eliasson, 2014)

Gothenburg introduced a congestion fee in 2013, with similar purposes as the one in Stockholm. Therefore, including sample years where Gothenburg was affected by a traffic tax would be a cause for concern for the analysis. Limiting the years of the study up to 2012 would thus allow Gothenburg to be included in the donor pool.

Theoretical framework

Traffic congestion, pollution and CO_2 emissions constitute negative externalities induced by the use of cars. A negative externality occurs when the production or consumption of a good causes welfare changes for someone other than the producer or consumer, i.e. a third party (Varian 2014: 666). As a consequence, this cost is not internalized and is therefore borne by society. In this case, the market becomes inefficient, leading to a market failure where the free market does not achieve an optimal use of society's resources (Krugman & Wells 2013: 121).

The introduction of a carbon tax or Pigouvian tax can be an effective tool to internalize and therefore compensate for the damages caused by the negative externalities. This theoretical idea has been developed by the English economist Arthur C. Pigou. Kolstad (2011) defines a Pigouvian fee as “A Pigouvian fee is an emission fee exactly equal to the aggregate marginal damage caused by the emissions when evaluated at the efficient level of pollution” (Kolstad 2011: 236). While the Stockholm congestion tax in itself is not a carbon tax nor a tax on emissions, it does however aim to internalize negative externalities, including those with an environmental impact, and therefore it seems relevant to this analysis.

4 Proposed data

The study would use annual data for the years 2000-2012. Excluding the intervention year, the sample includes panel data from 6 years before treatment and 6 years post-treatment. The years should be enough to construct a suitable pre-intervention trend, as well as for analyzing the outcome of the tax a few years after its implementation.

The donor pool that makes up the synthetic control group would consist of various major European cities along with their associated values on different covariates. The donor pool cities would mainly be chosen based on similarities to Stockholm, such as by their different means of transportation and their population sizes.

For Stockholm and the Swedish city of Gothenburg, the data for emissions per capita from passenger cars (which is the outcome variable) as well as all predictor variables for the examined years are accessible at SMHI and SCB. For other major European cities, emissions data and data for the relevant predictor variables most likely exist, and the first sources to consider would be the respective national traffic and statistical agencies. An important aspect to keep in mind would be to make sure that cities that have implemented similar traffic taxes during the sample period are excluded from the data. These would be cities such as London, and Riga (Milan implemented theirs in 2012). In general, the more suitable cities with accessible data the better, since it would allow for more flexibility in the creation of the synthetic control group.

However, there could be cause for concern about choosing the donor pool on European cities in terms of data accessibility. Getting accessible data from many cities in different countries would be time-costly, and there is no guarantee that some potentially suitable cities are available.

Would this actually be the case, an alternative proposal for this study would be to instead choose the donor pool using Swedish cities. All relevant data for Swedish cities on the respective county-level are accessible at SCB, both for the outcome variable and for the key predictor variables. The advantage of this alternative donor pool is that all the Swedish cities are similarly affected by external shocks that might affect emissions. The drawback would however be that Stockholm, the treated city, is the only Swedish city with a fully developed subway system and that also has a large variety of transportation options for commuters. Using a donor pool of major European cities would therefore deal with this issue, and could thus be more appropriate for this study. One concern of this would be the need to control for external shocks that might affect the treatment and control in different ways. The most suitable solution for this would be to choose the donor cities such that shocks, for example the financial crisis in 2009, affects the cities in relatively similar patterns.

What follows is a brief summary of the variables that would be used in the study. The outcome variable is annual CO_2 emissions per capita from passenger cars. The reason for using data from passenger cars is that heavier vehicles such as trucks were exempt from the tax.

The rest of the variables are predictors of emissions per capita dependent variable. For the purpose of creating the synthetic control, these predictors need to be normalized - in this case to per capita levels - to fit the dependent variable. Table 1 below presents a list of different proposed predictor variables that might be suitable to use for this particular study. The variables are based on economic intuition, but also from the argumentation in previous studies, such as Andersson (2019) and Percoco (2013). For simplicity, they are organized into three categories: *the economy*, *population* and *traffic*.

The economy	Population	Traffic
GRP per capita	Population size	Traffic volume per capita
Average income per capita	Unemployment rate	Number of car owners per capita
Gasoline consumption per capita	Share of population in urban areas	Newly registered EVs per capita
		Newly registered ethanol cars per capita

Table 1: proposed predictors of CO_2 emissions per capita for the synthetic control method. Most of the variables are normalized to per capita and at city-level. Note that this list contains suggested variables.

5 Method

Many studies that evaluate the implementation of different tax policies around a threshold commonly use the difference-in-differences (DiD) method. This method allows one to take advantage of the time differences in the data to eliminate bias from unobserved time-invariant covariates that otherwise would affect the outcome variable. For identification, the DiD is heavily reliant upon the key assumption of *parallel trends*, which in itself can be hard to validate (Andersson, 2019).

The main advantage of the synthetic control method is that, compared to the DiD, it does not rely on the parallel trends assumption for inference. By allowing unobserved covariates to vary over time, the synthetic control method relaxes the parallel trends assumption. Furthermore, while it is essential to hold the predictors of the outcome variable constant in the DiD, they are instead included in the synthetic control, where their predictive power is weighted and used to create a control group that most resembles the counterfactual (Abadie et al., 2010; Andersson, 2019).

To summarize it briefly, the idea of the synthetic control method is to get data on the pre-treatment characteristics of the outcome variable, which all are chosen from a donor pool consisting of cities other than Stockholm. Thereafter, one gets a weighted average of these characteristics in order to create a control group that very similarly resembles the treatment unit. The synthetic control group will be used as the counterfactual, which will allow us to estimate the causal effect of the Stockholm congestion tax on emissions.

Identifying assumptions

The synthetic control approach that we use requires a number of key assumptions (Abadie et al., 2010; Abadie and Gardeazabal, 2003; Bouttell et al., 2018).

Firstly, *no units in the donor pool should be affected by a similar tax policy*. In other words, when constructing the control group, it is important that all cities in the donor pool are unaffected by a similar traffic tax in order to avoid bias. Therefore, we remove any cities that have implemented congestion fees from the donor pool.

Secondly, *the treatment group and the control group should share similar characteristics.* This means that we build ”Synthetic Stockholm” from a set of variables that are similar to the actual treatment group in order for the synthetic control to reflect the counterfactual.

Thirdly, *there are no spillover effects of the intervention policy into the control units*. The Stockholm tax should thus not have an impact on any of the cities that make up the donor pool. This would be controlled using the in-space validity check (described more below under ”Validity tests”).

Creating the donor pool

As previously mentioned, the panel data would consist of characteristics from different cities, where Stockholm would be the city affected by the treatment tax. The rest of the cities in the dataset, which all are unaffected by any similar treatment policy, would be used to create the ”Synthetic Stockholm”. This is done by assigning weighted averages of the control cities in the donor pool. Some of the predictors of CO_2 emissions will thus be assigned more weight than others, which additionally implies that some cities will be given more influence than others in the control group (Bouttell et al., 2018).

In other terms, what we would do is choose optimal weights, W*, that minimize the difference between the pre-intervention characteristics of the treatment unit and the synthetic control unit (Abadie et al., 2010; Abadie et al., 2015). This is explained in equation (1).

$$\sum_{m=1}^{k} v_m (X_{1m} - X_{0m}\mathrm{W})^2 \qquad (1)$$

Where $X_{1m} - X_{0m}W$ is the pre-treatment difference between the two groups for the *m*-th variable, and v_m is a weight for the relative importance of said *m*-th variable for *m* = 1, …, *k*, as a predictor of CO_2 emissions.

The difference mentioned above is measured by the root mean square prediction error (RMSPE). The last step of the donor pool creation would be to choose the optimal vector V of the assigned weights to minimize the RMSPE, as recommended by Abadie et al. (2015). This is described in equation (2), where T_0 are the number of pre-intervention periods.

$$\mathrm{RMSPE} = \left(\frac{1}{T_0}\sum_{t=1}^{T_0}\left(Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt}\right)^2\right)^{\frac{1}{2}} \qquad (2)$$

Estimation of the Stockholm tax

The effect of the Stockholm congestion tax on CO_2 emissions will be estimated by equations (3) and (4). First, one estimates emissions, $\hat{Y}_{1t}^{N}$, for the synthetic control unit for the post-intervention period, t > T_0, as in equation (3). Thereafter the effect of the congestion tax, $\widehat{\tau_{it}}$, will be the difference in emissions between Stockholm, Y_{it}^{1}, and Synthetic Stockholm, $\hat{Y}_{1t}^{N}$, given by equation (4).

$$\hat{Y}_{1t}^{N} = \sum_{j=2}^{j+1} w_j Y_{jt} \qquad (3)$$

$$\widehat{\tau_{it}} = Y_{it}^{1} - \hat{Y}_{it}^{N} \qquad (4)$$

Where the donor pool cities are given by $j = 2,\ldots, j+1$, and the treated city Stockholm is denoted by j =1 and is excluded from equation (3).

Validity tests

There are three suitable tests needed for inference in the synthetic control approach. These are *in-time placebo, in-space placebo*, and *leave-one-out test*, and would all be done after the estimation process (Abadie et al., 2010; Andersson, 2019; Bouttell et al., 2018).

In-time placebo

This is done by shifting the year of treatment to an earlier year, thus creating a placebo-treatment. We want to check that this placebo-treatment year doesn't result in a post-placebo-treatment divergence between the treatment and the synthetic control. An example would thus be to check if the Stockholm congestion tax would have had an effect if we pretend that it was implemented in, for example, 2000 or 2002. Seeing a change in the trends would be a concern, as it would likely be a sign of bias and thus cast doubt that we are estimating the causal effect (Andersson, 2019).

In-space placebo

Use another city from the donor pool as treatment and create a synthetic control for this city. Then repeat the process for each city in the donor pool. For robustness, we want to check that this placebo-treatment city is not affected by the Stockholm tax. In fact, if they are affected by the tax (in which they should not be), we delete them from the donor pool. This test further allows for the calculation of p-values by measuring the ratio of the RMSPE (Andersson, 2019).

Leave-one-out

The idea is to leave a city with influential weight out of the donor pool in order to see if the outcome of the donor pool is mainly driven by one influential unit (Andersson, 2019; Bouttell et al., 2018).

Limitations

Limitations of the proposed method are discussed in this section. Firstly, the credibility of the synthetic method is based on how well a fit the control group is for the treatment group in the pre-intervention period. This becomes increasingly difficult if Stockholm is an outlier (Bouttell et al., 2018). I would argue however that there is no clear reason to believe Stockholm to be an outlier when comparing with characteristics of other major European cities. Given that we would choose the donor pool of cities with relatively similar characteristics as Stockholm, we would significantly minimize the possibility of Stockholm being an outlier. Secondly, no city in the donor pool should be affected by a similar policy, and there should be no spillover effects from the Stockholm tax to a control city. This would be fairly easy to control for by using the in-space and leave-one-out placebo tests. Thirdly, an important aspect to control for would be that the predictor variables for cities in the donor pool must have similar characteristics as the treatment city (Abadie et al., 2010; Bouttell et al., 2018). Just as in the previous points however, this would pose no large problems. That is, assuming that we choose the donor pool based on relative similarities in the predictors of CO_2 emissions, while also checking the validity of these controls in the placebo tests.

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