Research Proposal

of 41783 - Seminar 5

London School of Economics

The effect of Low Emission Zones in economic outputs: A synthetic control approach to German cities.

Abstract

Air pollution is a growing issue in health and policy initiatives and Low Emission Zones (LEZ) have proven popular and useful to reduce it in European cities. While these policies are criticised for "hurting the economy", recent literature indicates how air pollution negatively affects inputs of production, making LEZs a potential contributor to economic growth. To solve this contradiction from a program evaluation perspective, I propose the use of a Synthetic Control method as introduced by Abadie and Gardeazabal (2003) to study German cities's LEZs effects in the local economy. This research can provide a concrete answer to a pressing question for local authorities, academics and the broad public by providing specific estimates, accounting for the heterogeneity of implementation formulas, spill-over effects and transmission mechanisms.

ADD THE WORD COUNT, SHOW FEEDBACK and REVISE LAST SUBMISSION

NOTE: "you are permitted to re-use sections of text from your first MY400/500 assignment (and of that assignment only) verbatim in your second assignment..."

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Keywords — Synthetic Control, Difference in differences, Traffic Management Systems, Low Emission Zones, Germany, Cities, Economic Geography

1 Literature review

To add: [ ] % of city pollution that comes from cars (See Wolff), Measure of costs and benefits from European Council (document) and the one cited by Dechelepêtre.

Recent research estimates that 92% of the world's population lives in areas where levels of air pollution exceed the World Health Organization's air quality guidelines, with 3 million deaths a year being attributed to air pollution (Shaddick et al., 2018). In order to minimise these costs, substantial policy initiatives aimed at improving air quality have been implemented around the world. Cities and urban areas play a central role in this effort as virtually half of the world's total population - around 3 billion people - now live in urban settlements, a number that has greatly increased during the last 20 years (Cohen, 2006). This fast urbanization has resulted in increases of congestion and pollution and related health and economic costs.

In European cities, LEZ have proven popular when trying to improve air quality and comply with the increasingly strict EU regulations (Gehrsitz, 2017; Holman et al., 2015). Germany has been in the forefront of the application of these geographical restrictions to vehicles with most cities over 10-0 inhabitants having applied a LEZ from 2008 to 2013. These policies have been supported and standardised by the federal government and applied in different stages applying fines of 40-80€ and 1 demerit point in the central traffic registry (Gehrsitz, 2017).

According to classic economic theory, we would expect these policies to damage a city's economy as they involve taxes and prohibitions for certain vehicles, leading to claims of a "Jobs versus the Environment" trade-off as introduced by Morgenstern et al. (2002). LEZ' impact on economic outputs such as economic growth, profits and employment has been a constant concern of citizens and local officials. And their concern is not unjustified. All principal cities that constitute the backbone of the German economy have applied a LEZ (Berlin, Hannover, Munich, Köln, Dortmund and Stuttgart are some examples). It is crucial to know if Germany's economy has been affected by these predominant environmental measures to be able to develop benefit-cost analysis. However, the effects of reducing congestion and pollution might offset other economic costs.

This hypothesis is based on recent research on the effect of LEZ on increasing mobility (Kelly and Kelly, 2009) and decreasing health costs (Cesaroni et al., 2012) and air pollution Gehrsitz (2017); Wolff (2014) (who give results for German cities). Furthermore, recent studies suggest that air pollution reduces aggregate economic output (Dechezleprêtre, 2018; Hao et al., 2018). This can happen through various mechanisms such as increasing mortality (Xie et al., 2016), reducing productivity (Adhvaryu et al., 2014; Chang et al., 2016; Graff-Zivin and Neidell, 2012) and cognitive performance (Ebenstein et al., 2016; Roth, 2015; Zhang et al., 2018) or increasing absenteeism (Hanna and Oliva, 2015; Ransom and Pope, 1992).

In the European Union, all regional and national governments have been strongly incentiviced to pursue strong policy action by the mentioned european regulation by several EU council directives. The European Commission (EC) has opened infringement procedures against 16 Member States[1] and the EU Court of Justice has already handed down judgements in Bulgaria and Poland[2].

There is strong evidence too that a very significant proportion of pollution in cities comes from traffic, with 35-55% of PM10 particles coming from vehicles in the EU (Viana et al., 2008) and in Berlin a a 38% and 23% in traffic and backgrownd stations, respectively Lenschow et al. (2001) with german LEZ having significantly reduced particle pollution (Gehrsitz, 2017; Wolff, 2014).

For the availability of previous research, the standardisation of LEZ by the federal government and the availability of data already discussed, I am confident that German LEZ are the best subject of study I can have to understand the causal effects between a strong environmental policy such as LEZ and economic performance. To the best of my knowledge, there is no published work on the causal effect of over 100 European LEZ on aggregate economic performance.

2 Research Questions

Main question:

- What was the effect of the application of Low Emission Zones (LEZ) on Geman cities economies?

Complementary questions: *(subject to the adequacy of methods and time constraints)*

- What are the main transmission mechanisms that drive this effect and how much they influence the final economic output? This is avoidable
- Which sectors are more affected by the policy?
- What is the relative effect of different strengths of LEZ in Germany? Same methodology as previous german LEZ studies.

[1] Belgium, Bulgaria, the Czech Republic, Germany, Greece, Spain, France, Hungary, Italy, Latvia, Portugal, Poland, Romania, Sweden, Slovakia and Slovenia

[2] Commmunication from the EC, “A Europe that protects: Clean air for all”, accesible here: `https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52018DC0330&from=GA`

3 Data collection strategy

For this project I need data for treated regions (german cities that applied a LEZ) and the pool of control regions (german or other european cities that have not applied any similar measure) on: (1) Sufficient pre- and post-intervention aggregate data on outputs and predictors of outputs both to test the validity of the identification strategy and be able to see the short and mid term effects of the intervention. (2) Detailed description of the application of policies for all cities considered to correctly assign treatment and create a carefully selected the control pool clean of any similar intervention.

The data will come different sources and will be aggregated mainly by geographical location. First, Eurostat's collection of regional statistics available for NUTS regions[3] (from 2000 to 2018 and covering the whole of the EU) provides yearly statistics for the main dependent variables such as GDP and GVA per sector. Additionally, Eurostat provides local data on transmission mechanisms (predictors) and controls such as total employment, unemployment, science and technology statistics (trademarks and patents), business outputs and demographics[4]. Productivity is an especially important variable for my analysis as the literature suggests it is directly affected by pollution, for that reason a rough productivity measure could be constructed by dividing overall productivity by number of employed persons.

Secondly, the implementation of LEZ in Germany is well documented by the the German Environment Agency (Umweltbundesamt - UBA)[5]. Additionally, data on the implementation of LEZ and similar policies in European regions will come from specialized database from *UrbanAccessRegulations.eu* (both linked by the UBA and financed by the EC) and the "Green Zones" mobile application that informs professional carriers and drivers on the state of urban access regulations and LEZ in Europe[6]. The data are freely available in their web page and public App although it needed to be scrapped and re-structured. Public information and past studies on policies will help complete and review these external data sources. Finally, local air quality data will be gathered from satellite data from van Donkelaar et al. (2016) and air stations data from the AirBase of European air quality e-reporting (EEA) with access to the completeness of public air monitoring stations in the European Union (XXXX in total) This data will be de-weathered using the usual control variables or by specific R packages.

An extensive summary of the potential variables and an illustration of the NUTS regions

[3]NUTS, or Nomenclature of Territorial Units for Statistics, is a geographical code to reference the subdivisions of countries. Granularity varies by country but its especially good in Germany and follows natural cities boundaries.

[4]There is a vast amount of regional economic, demographic and environmental data at this geographical definition. Even if the information mentioned is enough to achieve the research aim of this proposal, I am confident that further data can be found to get a deeper understanding of the transmission mechanisms at play. A summary of the potential variables can be found in the Appendix.

[5]An ilustration of this data is available on the appendix' Figure 2.

[6]UrbanAccessRegulations.eu has been already used by Holman et al. (2015) as a source of data to review of the efficacy of European low emission zones to improve urban air quality.

can be found in the Appendix.

4 Data Analysis strategy

To answer the main question on the effect of LEZ in the city's various economic outputs I intend to use a Synthetic Control Method (SCM) such that the effects in each treated region can be quantified by constructing a synthetic control from all untreated regions both from Germany and the rest of the European Union. This method was introduced in Abadie and Gardeazabal (2003) to study the effect of conflict in the Basque Country's macroeconomic performance and is extensively described in Abadie et al. (2010)[7]. Even if the SCM has not yet been applied to cities' LEZ, previous related research has used very similar techniques. For example, Wolff (2014) and Gehrsitz (2017) applied differences-in-differences (DID) to estimate the causal effect of German LEZ in local air quality.

For DID, a valid control has to be chosen such that (1) it follows the same pre-treatment period path as the treated unit and (2) it has some theoretical and practical resemblances with the treated unit such that, in absence of the treatment, both would have continued to follow the same path. The SCM is similar from DID, both lay their main identification requirement on having similar trends before treatment and avoid making the assumption of an exogenous treatment assignment. Although DID allows for the presence of constant unobserved confounders (given they are constructed by taking time differences), the SCM allows the effects of confounding unobserved characteristics to vary with time (Abadie et al., 2010).

The SCM tries to avoid ambiguity on how comparison units are chosen and account for the uncertainty that they will indeed reproduce "the outcome trajectory that the affected units would have experienced in the absence of the intervention or event of interest" (Abadie et al., 2010). It does it by creating a synthetic control from a weighted average of non-treated units such that it best follows the pre-treatment path of the treated unit and it's as similar as possible in some major predictors of the output. An illustration from Abadie et al. (2015) is available at figure 3.

The SCM is especially appealing for comparative case studies for multiple reasons: (1) All estimations are done within the support of the data (no extrapolation) given it is constructed as a weighted average of treatment units. (2) We can clearly see the differences in

[7] Multiple methodologies build on the SCM and could be used in this research, some examples are the Generalized Synthetic Control Method that applies the methodology to multiple treated units (Xu, 2017) and Bayesian structural time-series models (Brodersen et al., 2015) developed in Google which use other Machine Learning procedures to estimate the counterfactual and it's credible interval. All 3 of them have author-developed packages in R or Python. Incluir la metodología de "effects of mediators". y posiblemente hablar de otras que usaré como Abadie and l'Hour (2019)

pre-treatment paths and characteristics between treated and synthetic control making possible to assess its internal validity.[8] (3) We know the weights of the control units that make the synthetic control, allowing us to evaluate their validity as controls.[9]

I intend to use each one of the 58 LEZ applied in Germany in the last 12 years (available in figure 2) as treatment to calculate both the heterogeneity of treatment effects and the average treatment effect on the treated. This gives 8-18 years of pre-treatment data to create the synthetic control and evaluate it's fit. The control pool will be constructed from all European cities of similar size and economic predictors as the treated cities.

4.1 Main Analysis

The main result would be the effect of LEZ in GDP but this will be decomposed and complemented by other estimates. The effects on the labour market would be modelled as following: given $GDP \equiv \frac{GDP}{Hours\ worked} * \frac{Hours\ Worked}{Employed\ Pop} * \frac{Employed\ pop}{Working\ age\ pop} * \frac{Working\ age\ pop}{Population} * Population$, then the main 6 causal effects to estimate (and their interpretation) are:

$$\overbrace{\frac{\partial ln(\text{GDP})}{\partial \text{LEZ}}}^{\text{Main effect}} = \overbrace{\frac{\partial ln(\text{GDP/Hours worked})}{\partial \text{LEZ}}}^{\text{Effect on productivity}} + \overbrace{\frac{\partial ln(\text{Hours worked/Employed pop})}{\partial \text{LEZ}}}^{\text{Effect on absentism or temporality}} + \underbrace{\frac{\partial ln(\text{Employed Pop/Working age pop})}{\partial \text{LEZ}}}_{\text{Effect on employment}} + \underbrace{\frac{\partial ln(\text{Working age pop/Population})}{\partial \text{LEZ}}}_{\text{Effect on the proportion of working age population}} + \underbrace{\frac{\partial ln(\text{Population})}{\partial \text{LEZ}}}_{\text{Effect on population}}.$$

Additionally, the main effects for each industry will be estimated together with other economic outcomes and possible mediators. This will help understand which sectors are more affected by this policy. Additional variables will include business growth, number of patents published, education levels (human capital), Investmentand pollution. The synthetic control method will be used to provide estimates of all these individual treatment effects.

[8]This allows us to make all decisions regarding the set of controls and predictors by looking at the pre-treatment fit with a measure such as Mean Squared Prediction error (MSPE). Given we don't need access to post-treatment data, we are safeguarded against specification searches and p-hacking.

[9]See tables 2 and 3 for illustrations from Abadie et al. (2015).

4.2 Mediation analysis

NOTE: Explain why mediation analysis is so important for my research. Based on theoretical mediation paths.

To answer how mediators influence the final effect of the policy I plan to use the Mediation Analysis Synthetic Control (MASC) introduced in Mellace and Pasquini (2019)[10]. To briefly explain their methodology first I need to set some bases on potential outcomes notation. For time t, unit i and treatment $D \in \{0, 1\}$, the set of values of the mediator would be $M_{it}(D)$. For example, a LEZ could be the treatment D, GDP could be the outcome Y_{it} and pollution could be a potential mediator M_{it}. Finally, the set of potential outcomes would be defined as $Y_{it}(D, M_{it}(D')) \equiv Y_{it}^{D,D'}$ for $D, D' \in \{0, 1\}$.

MASC creates an estimate of $Y_{it}^{0,1}$ by "re-weighting the control unit post-intervention outcomes by choosing weights that minimize the distance between treated and control pre-intervention observable characteristics as well as post-intervention values of the mediator" (Mellace and Pasquini, 2019). For example, they would compare the actual GDP of Berlin with the synthetic control that follows best its pre-LEZ GDP and its post-LEZ pollution, looking at what would have happened to Berlin in the absence of intervention but with the mediator value characteristic of the intervention ($M_{it}(D = 0)$ and $Y_{it}^{0,1}$).

With the estimate of $Y_{it}^{0,0}$ from the usual SCM and the data from the treated $Y_{it}^{1,1}$ they define the direct effect as $Y_{it}^{1,1} - Y_{it}^{0,1}$, the indirect (or mediated) effect as $Y_{it}^{0,1} - Y_{it}^{0,0}$ and the total effect as $Y_{it}^{1,1} - Y_{it}^{0,0}$. Only one additional assumption must be taken to apply MASC, that there is some overlap in the post-intervention values of the mediatior between treated and the control pool. To continue with the Berlin example, that some controls have similar decreases in pollution as the ones experienced in Berlin after the application of a LEZ. The plausibility of this assumption can be graphically assessed by looking at the overlap in the pre-intervention period between the observed outcome, Y_{it}, and the synthetic outcome $Y_{it}^{0,1}$ as they should be no gap before the intervention.

Potentially, and for large cities such as London where different TMS are in place and the NUTS regions give sufficient resolution, a study of the relative impact of different TMS on economic output is possible by comparing regions where the application (A) differs.

A study on the spill-over effects of TMS is also possible by comparing areas that surround treated and non-treated urban areas, following the experimentalist paradigm recommended by Gibbons and Overman (2012).

[10]Although this is still a working paper, both the authors of MASC and my academic advisor believe that it suitable for this research. I am in contact with them and have access to their code in R.

4.3 Requisites, assumptions and robustness tests

Following technical and practical guidance from Abadie et al. (2010) and Abadie (2019), careful thought has been given to the needed contextual requirements and assumptions of the SCM. I discuss them below.

LISTA DE LAS ASSUMPTIONS Y SUS POSIBLES FALLOS. LUEGO EXPLICAR CÓMO PIENSO CONTROLAR POR ESTOS. (MIRAR NOTAS RAÚL)

Identifying requirements:

1. **Sizeable effect:** The size of the policies effect should be bigger than the individual transitory shocks to be able to identify them. From preliminary inspection of the data I expect individual transitory shocks of around 0.5-2% of regional GDP per capita[11]. The closest I could find on the effect of LEZ on GDP is from the german pro-business Institute for Retail Research that estimates a 7% decrease in customers in stores located within a city center after the introduction of a LEZ. CITE from Gehrsitz (2017) (Lindstaedt, 2009). I expect the mediated effect pollution reduction associated with the introduction of a LEZ to be around 1% of GDP pollution given the estimates of Dechezleprêtre (2018) and Gehrsitz (2017).

2. **Non interference between units/cities:** I guide myself with the research done by Wolff (2014) and Gehrsitz (2017) on the effect of german LEZ on pollution, health and vehicle composition and the spillover effects present within and between cities. A summary of their findings is as follows: (1) Wolff (2014) concludes that a LEZ also reduces pollution in surrounding areas but this is only significant with big and strict LEZ, such as the one of Berlin. Gehrsitz (2017) finds a non-signifficant effect on pollution reduction. (2) Wolff (2014) show that the application of a LEZ correlates with a change towards cleaner vehicles and cities close to a LEZ also seem experience this, especially their commercial vehicles. The correlation is close to a 1-to-5% change in the vehicle composition of a nearby city. Nevertheless Gehrsitz (2017) looks for a causal effect on pollution reduction and concludes that "The introduction of an LEZ in a nearby city does not appear to translate into reductions in fine particulate pollution." and adds that his results "indicate that any violations of the SUTVA due to spillovers are unlikely to induce substantial bias into the main results". In conclusion, some spillovers are possible in very specific cases for the outskirts of a large LEZ (that will be included in my NUTS3 regions), but unlikely and economically insignificant for nearby cities. On the other hand, close cities might be especially good controls if these spillovers are not present. For this reason I will do robustness tests by restricting my control pool, these are explained on the "Robustness and diagnosis checks" section.

[11] If the noise in the outcome variables is relatively high, it's possible to use de-noising techniques such as the ones proposed by **?**.

3. **Valid comparison group:** To construct a valid comparison group I will construct a set of European cities that have not applied similar measures or suffered large idiosyncratic shocks during the study period, avoiding biases from confounders and interpolation[12]. To control for that I will look for large shocks on aggregate GDP and pollution for all cities, and exclude those who are listed in the UrbanAccessRegulations and "Green Zones" databases and perform robustness tests excluding German cities that have applied other Environmental Action Plans.

4. **No anticipation:** LEZ in general, and also in Germany, were usually publicised before being enacted specifically to incentivise the public to upgrade their vehicles.As an example, Wolff (2014) shows how the city of Regensburg had a very strong relative increase in green-labelled cars after the announcement of the LEZ but before its application. This will be accounted by creating an "announced period", and setting it as the start of the treatment.

Robustness and diagnosis checks:

1. As is documented in the literature the main two robustness tests for SCM are regarding:
   (a) The choice of units in the donor pool, for which I will restrict my control pool to cities outside a 50-100km radius from a LEZ and unite the Rhine-Ruhr metropolitan area as an unique city.[13]. Additionally I plan to perform a leave-one-out re-analysis to check if the inclusion of any individual controls is driving the results[14]).
   (b) The choice of predictors of the outcome variable, given they specify which macroeconomic variabels the SCM should follow more closely in the pre-treatment period. Given I am studying overall economic performance I will closely follow the predictors from Abadie and Gardeazabal (2003) and Abadie et al. (2015). Furthermore, I can tests how different combinations of them reduce or increase the pre-treatment RMSE and choose accordingly.

2. Finally, in-time placebo treatments as in Abadie et al. (2015) will be done years before the announcement of the LEZ plans to test if highly forward-looking agents decide to change their vehicles even before the city announcing its plans for a LEZ.

[12]To control for interpolation biases Abadie and L'Hour (2019) propose including a penalty term to the objective function that depends on the discrepancies between the characteristics of the treated unit and the units included in the synthetic control. Their code is available on GitHub.

[13]The relative sizes of cities could also be considered ($GDP_{treated}/GDP_{control}$) as bigger cities have more influence in small ones. Furthermore, Eurostat's "Functioning urban areas", where the limits of a city's influence of a is clearly delimited in space, could also be used to restrict controls to those outside the given area. **INCLUDE here and in data sources, (different levels of aggregation) SEE NOTES**.

[14]This is done by re-computing the SCM estimates each time without one control that helped create the synthetic control. If a control strongly changes the estimates it might have probably had idiosyncratic shocks during the time of the study.

5 Potential impact and relevance of the study

This research can provide a comprehensive answer to an already pressing question for local authorities, academics and the broad public. The study results can be used to have a better understanding of the policy's effects by providing specific estimates for the effect of German LEZ in their cities economy accounting for transmission mechanisms. These can help to construct more effective and fair public policies on LEZ that take into account the results in similar citiesAdditionally, the results can potentially get the attention of policy makers and business leaders as they investigate local short-term effects that concerns them directly.

NOTE: Standarized cities, Multiple cities, past research and % of german GDP in those cities. Accounting for mediator effects and an analysis on the labour effects of the policy.

Furthermore, it could also promote further research looking at the potential effect of LEZ in developing urban settlements in low and middle income countries, where the costs of pollution appear to be higher and policy advice is much needed.

6 Limitations

Limitations of the results are derived from assumptions of the model and its functional form. With a well specified Synthetic Control I can claim the policy effects in aggregate output and its different labour components. Furthermore, even if I can find The mechanisms that drive this change would still be in question for lack of more detailed micro data regarding businesses. (or size of idiosyncratic shocks that would obscure economically significant effects of 0.5-2% of GDP and render non-significant estimates) Furthermore, even though an intuition on the ranges of effect size can be extracted from Germany's example, the results can only be interpreted for this specific case study. Regarding contingency plans, if I can't get a convincing argument behind the assumptions of non-interference between units and omitted variable bias I should find other case study and data to estimate the policy effect.

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Appendices

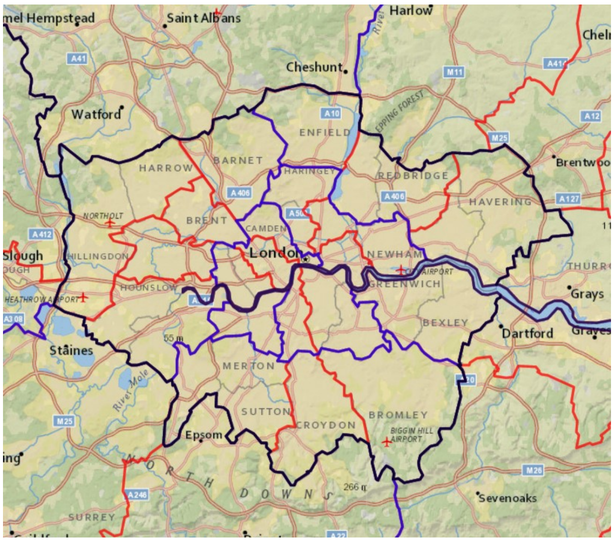
Table 1: Potential analysis variables with their source, geographic and time coverage.

Variable	Coverage	Geography	Start	End	Delta	Source
Outcomes (Y):						
Gross value added (GVA) by Industry	UK	NUTS 3	1998	2017	1 year	Office of National Statistics (ONS)
GVA at basic prices by NACE activites	EU	NUTS 3	1995	2017	1 year	Eurostat
GDP	UK	NUTS 3	1998	2017	1 year	ONS
GDP	EU	NUTS 3	2000	2017	1 year	Eurostat
Total GDP at current prices	EU	NUTS 4 (LAU 1)	2000	2017	1 year	Eurostat
Spatial variation (X):						
Boundaries of TMS zones	EU	georeferenced	Most recent			urbanaccessregulations.eu
Boundaries of TMS zones	EU	georeferenced	Most recent			“Green-Zones” App
Boundaries of TMS zones	Germany	georeferenced	Most recent			“Umweltzone” App
Boundaries of TMS zones and details on their implementation	EU	“Described”	All	All	All	Official and legal documents
Boundaries of TMS zones and details on their implementation	EU	georeferenced	Partial	Partial		openstreetmap.org
Details on TMS’s implementation	Germany	“Described”	All	2017	1 month	Gehrsitz (2017) and Wolff (2014)
Transmission mechanisms (secondary Y):						
Employment (’000 persons) by NACE	EU	NUTS 3	1995	2017	1 year	Eurostat
Employer business demography by NACE Rev. 2	EU	NUTS 3	2008	2016	1 year	Eurostat
Employer business demography by size class	EU	NUTS 3	2008	2016	1 year	Eurostat
Business demography and high growth enterprise by NACE Rev. 2	EU	NUTS 3	2008	2016	1 year	Eurostat
Business demography by size class	EU	NUTS 3	2008	2016	1 year	Eurostat
Science and Tech statistics	EU	NUTS 3			1 year	Eurostat
Community design (CD) applications	EU	NUTS 3	2003	2016	1 year	Eurostat
Patent applications to the EPO by priority, IPC, sections and classes	EU	NUTS 3	1977	2012	1 year	Eurostat
High-tech patent applications to the EPO by priority year	EU	NUTS 3	1977	2012	1 year	Eurostat
Patent applications to the EPO by priority year	EU	NUTS 3	1977	2012	1 year	Eurostat
Business Demographics and Survival Rates	London	Borough	2002	2018	1 year	ONS
VAT enterprices by turover	London	Borough	2003	2019	1 year	ONS
Real labour productivity	UK	LEPs	2004	2017	1 year	ONS
Productivity	UK	Cities	2004	2017	1 year	ONS
PM2.5 mean concentration	EU	0.01^o x 0.01^o	2000	2017	1 year	van Donkelaar et al. (2016)
PM2.5 concentration	EU	$10km^2$	2008	2015	dialy	CAMS
Air pollutants concentration summary	EU	Weather Stations	2013	2018	1 year	EEA
Air pollutants concentration	EU	Weather Stations	2013	2018	dialy	EEA
Other variables (mostly control):						
Household income	UK	MSOA	2011	2016	2 years	ONS
Deaths (total)	EU	NUTS 3	1990	2017	1 year	Eurostat
Population change	EU	NUTS 3	2000	2018	1 year	Eurostat
Land use (degree of urbanization)	EU	NUTS 3	2015	2020	5 years	JRC
Electricity and Gas consumption	UK	LSOA	2016	2017	1 year	ONS
Live births	EU	NUTS 3	1990	2017	1 year	Eurostat
Area (m^3)	EU	NUTS 3	1990	2015	1 year	Eurostat
Population / age, sex	EU	NUTS 3	1990	2018	1 year	Eurostat
Live births / age mother	EU	NUTS 3	1990	2017	1 year	Eurostat
Fertility rate	EU	NUTS 3	1990	2017	1 year	Eurostat
Age dependency ratio by age class	EU	NUTS 3	2014	2018	1 year	Eurostat
Young age dependency ratio	EU	NUTS 6 (city)	2000	2018	1 year	Eurostat
Share of transport means to work (imperfect)	EU	NUTS 6 (city)	2001	2012	1 year	Eurostat
Cars/1000 persons (imperfect)	EU	NUTS 5 (LAU 2)	2002	2012	1 year	Eurostat
Shape files of NUTS and LAU regions:						
Shape Files	EU	NUTS and LAU	All	All	All	Eurostat

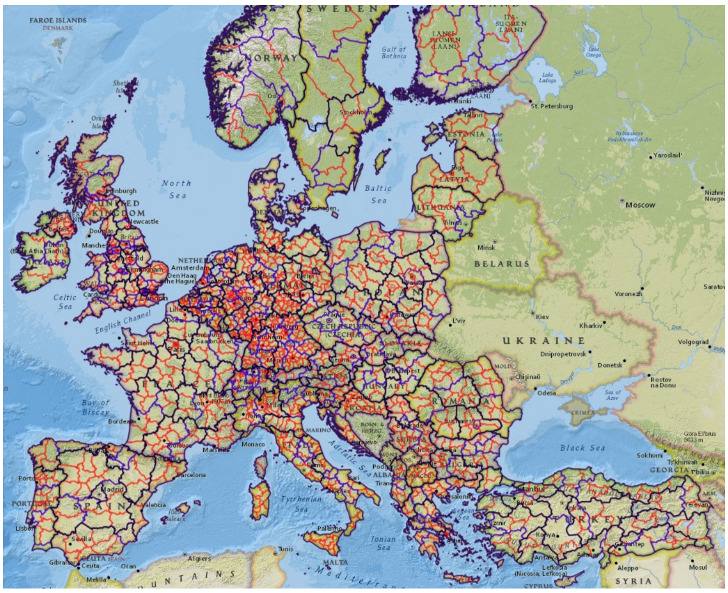
(a) Madrid (1 NUTS1)

(b) Paris (4 NUTS3)

(c) Budapest (1 NUTS1)



(d) London (22 NUTS3, 1 NUTS1)



(e) Main coverage of NUTS 3 zones

Figure 1: Main coverage of NUTS zones across Europe, with examples of cities. Borders of NUTS 1, 2 and 3 regions are coloured in black, blue and red, respectively.
Only germany + Rhine-Ruhr metropolitan area + Berlin, Hannover and Münich
Source: Eurostat and own work.

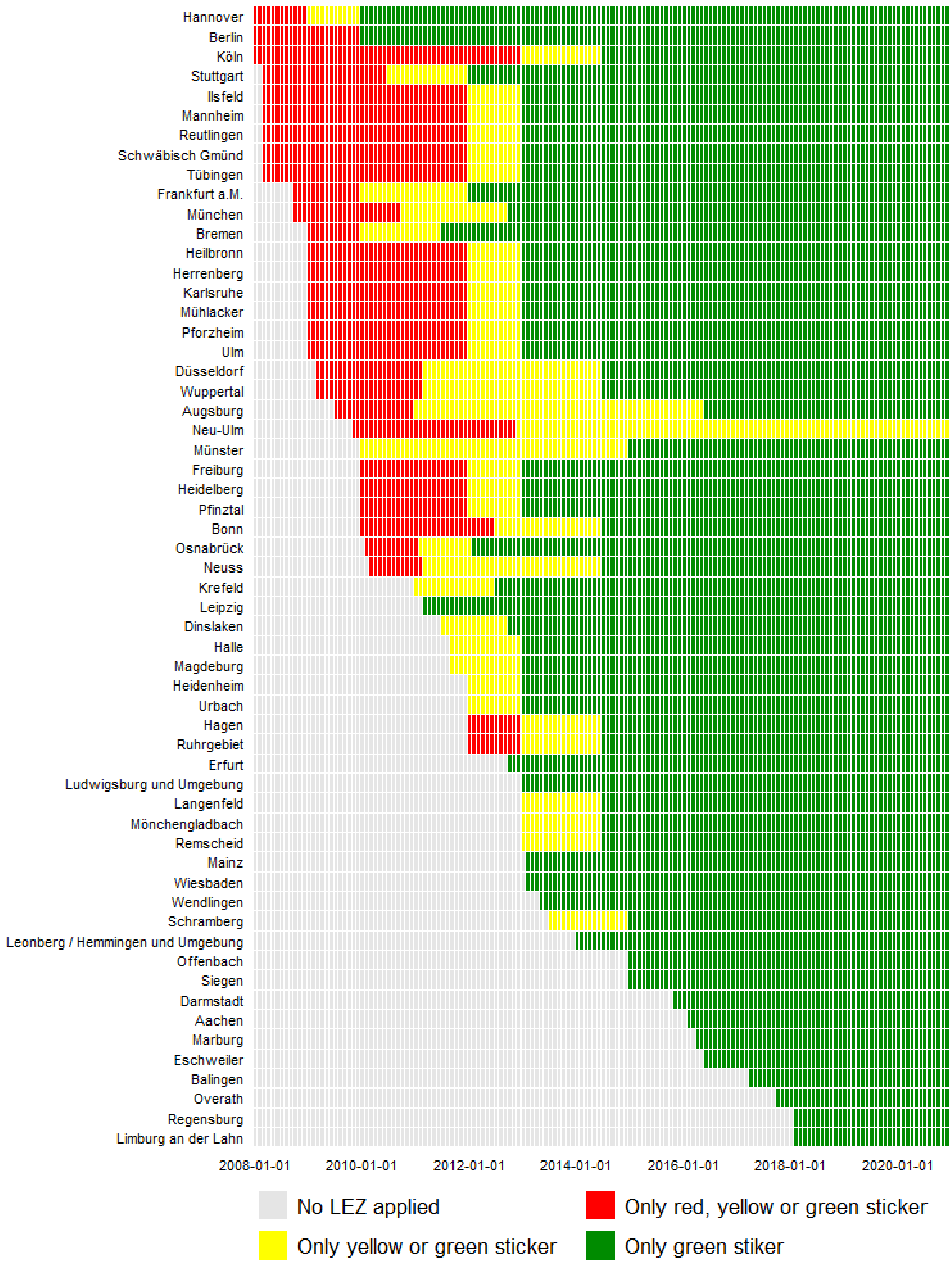


Figure 2: Application of LEZ in Germany by category of environmental stickers allowed and month of the year.
Source: Umweltbundesamt and my own work.

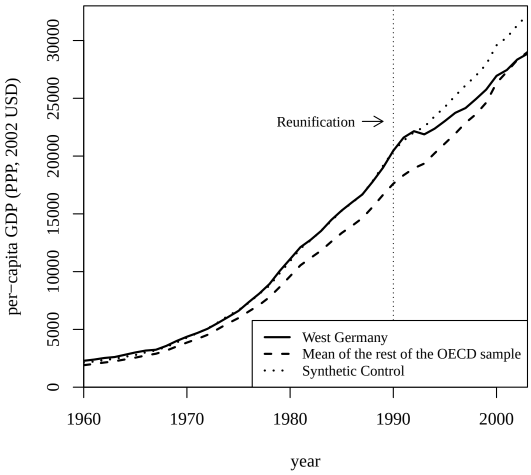


Figure 3: GDP per capita of West Germany, the mean of the rest of the control pool and the synthetic control in Abadie et al. (2015) (modified graph for illustration purposes)

	West Germany	Synthetic West Germany	Rest of OECD Sample
GDP per-capita	15808.9	15802.2	8021.1
Trade openness	56.8	56.9	31.9
Inflation rate	2.6	3.5	7.4
Industry share	34.5	34.4	34.2
Schooling	55.5	55.2	44.1
Investment rate	27.0	27.0	25.9

Table 2

Countries	Weights	Countries	Weights
Australia	-	Netherlands	0.09
Austria	0.42	New Zealand	-
Belgium	-	Norway	-
Denmark	-	Portugal	-
France	-	Spain	-
Greece	-	Switzerland	0.11
Italy	-	UK	-
Japan	0.16	USA	0.22

Table 3