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Agglomeration Effects

Studying Agglomeration Effects from Norwegian Hydroelectricity Plants

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Abstract

This thesis aims to answer the research question *"To what extent did the shocks to economic activity and population following openings of Norwegian hydroelectricity plants in the early 20*th *century lead to long run agglomeration effects?"*. The question is answered using data on population density and taxable income in 67 Norwegian municipalities in the period between 1876 and 2013. We utilize the fact that hydroelectricity plants opened before transportation of electricity over large distances was possible provide temporary shocks to population density and economic activity. Using a combination of the synthetic control method and the rolling out approach we estimate both short- and long run effects following the openings of hydroelectricity plants. The main conclusion is that opening hydroelectricity plants lead to significant short run effects in several of the municipalities in the dataset, but that the evidence for long run agglomeration effects is weak.

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1 Introduction

People and economic activity tend to cluster in most countries. Throughout history there have been numerous examples of such clusters, ranging from Athens in ancient Greece, through Rome, to modern day metropolises like London, Tokyo and New York. Despite significant reductions in transportation costs for people and goods in recent decades, the degree of clustering continues to increase (Glaeser 2010). This implies that there are strong forces that compel us to locate in close proximity to others. Understanding this development is interesting both from a theoretical perspective, and because of the real world implications it has. Consequently, there is a substantial literature trying to explain the development, and a number of possible explanations have been presented. Dating back to Simon (1955), one theory, known as the random growth theory, states that economic activity is distributed simply based on random factors. A second theory, known as the locational fundamentals theory, argues that growth occurs in some locations due to natural advantages (Davis and Weinstein 2002). A third theory, known as the increasing returns theory, states that "advantages of size may arise from knowledge spillovers, labor-market pooling, or the advantages of proximity for both suppliers and demanders in a world of costly trade" (Davis and Weinstein 2002, p. 1269).

The types of mechanisms described in the third theory are known as agglomeration effects in the literature. Agglomeration effects can be defined as "benefits that come when firms and people locate near one another together in cities and industrial clusters" (Glaeser 2010, p. 1). Examples of such mechanisms include knowledge spillovers between IT companies in Silicon Valley and increased productivity caused by a better availability of skilled labor. Agglomeration effects are particularly interesting to study, because unlike the other two possible explanations, they can be influenced and taken advantage of by policy makers. The goal of this thesis is to contribute to the literature by analyzing agglomeration effects in a Norwegian context.

Studying agglomeration effects in a Norwegian context is interesting for a number of reasons. Firstly, unlike many other countries where agglomeration effects have been studied, Norway is a mountainous country with many scattered small cities, meaning that we can study smaller population sizes than most other studies. Studying different population sizes will allow us to contribute to the debate surrounding the existence and size of agglomeration effects. A further reason why studying agglomeration effects in the Norwegian context is interesting is that it is a goal in Norwegian politics that the government should make it desirable to live in rural areas (Norwegian Ministry of Local Government and Modernisation 2015). Hence, understanding the mechanisms deciding where economic activity is located is interesting for policy makers in Norway as well as other countries with similar goals. Additionally, there is an ongoing debate in Norway regarding the trade-off between allowing businesses to pollute in remote areas and the increased employment opportunities that the businesses will offer to the local community. Examples of such cases are oil drilling in the northern parts of the country, environmental damages caused by fish farming as well as allowing mining companies to pollute fjords by dumping waste. A key point in this debate is weighing the possible long run benefits of the increased activity against the costs of pollution. Thus, knowledge regarding the size of agglomeration effects is important when making such decisions.

1.1 Research Question

As mentioned, our thesis is aimed at analyzing the size of agglomeration effects in Norway. An issue when studying agglomeration effects is that while agglomeration may give rise to productivity increases, productivity increases may also give increased agglomeration (Ciccone 2002). This possible reverse causality makes estimating the size of agglomeration effects challenging. A key point in our analysis is therefore that hydroelectricity plants in the early 20^{th} century provided temporary shocks to population and economic activity in several municipalities. This makes it possible to estimate agglomeration effects without having the analysis confounded by reverse causality. Consequently, our research question is:

"To what extent did the shocks to economic activity and population following openings of Norwegian hydroelectricity plants in the early 20^{th} century lead to long run agglomeration effects?".

The question will be answered using a combination of econometric methods and data on population and taxable income from Norway.

1.2 Outline

The rest of the thesis is organized in the following way; in section 2, we go into further detail by looking at previous literature related to economic clustering and agglomeration. In section 3, we present the theoretical framework that our analysis is based upon. In section 4, we discuss the historical background of hydroelectricity and the electricity grid in Norway. In section 5, the methodological approach of the thesis is presented and discussed. Section 6 presents the data used in the analysis. In section 7, we present two case studies to support the validity of the theoretical framework of the analysis. In section 8, we present the empirical analysis and our results. In section 9, we discuss the results and potential issues in the analysis. Lastly, section 10 contains our concluding remarks.

2 Previous Literature

The literature analyzing agglomeration effects is extensive. An example of a paper looking at such effects is Bleakley and Lin (2012). They look at US portage sites, locations where commerce arose due to geographical conditions and transportation of goods. More specifically, portage sites were locations where merchants met because they had to carry their boats or cargo between navigable waterways or to avoid obstacles such as waterfalls (Bleakley and Lin 2012, p. 2). An example of such a location is Louisville, Kentucky, where merchants had to disembark due to falls in the Ohio river. This lead to an increase in activity in the Louisville area, and Louisville still remains a population center. The study hinges on the fact that portage sites at some point in time had a natural advantage that lead to commerce, but that this natural advantage disappeared at some point in time due to changes in how goods were transported. The authors find that the locations in their sample that at one point were portage sites were more likely to be population centers even long after their natural advantage disappeared. This indicates that population- and economic growth exhibits a degree of persistence, or path dependence as they call it, which is in line with agglomeration effects.

Greenstone, Hornbeck, and Moretti (2010) analyze agglomeration effects by comparing the outcomes of manufacturing plants in similar counties where the only difference is that a large manufacturing plant opens in one of the counties. The reasoning behind this research design is that if agglomeration effects are present, the opening of a large manufacturing plant should have a positive effect on the other manufacturing plants in that county as well (due to synergies etc.), while there should be no such effect in the county not getting a plant. They find that after five years, the total factor productivity in plants in counties where large manufacturing plants opened was 12 percent higher than in counties where no new plant was opened. This indicates a presence of agglomeration effects. They further find that the effects are strongest for plants using the same type of input factors (labor and technology) as the new plant.

Kline and Moretti (2014) analyze agglomeration effects by investigating the long run effects of the investments of the Tennessee Valley Authority (TVA) program. The TVA program was an ambitious federal investment project in 163 counties in the Tennessee area aimed at creating economic growth in the region. Some of the most salient consequences of the program were investments aimed at constructing hydroelectricity plants and other infrastructure in the period between 1930 and 1960. Using Oaxaca-Blinder regressions they compare the performance of TVA counties with similar counties located elsewhere. Their results indicate that the program had large positive effects on the manufacturing industry also beyond the time scope of the program, indicating agglomeration effects.

A paper using a similar approach is Severnini (2014). His research design relies on the assumption that counties that had hydroelectricity plants installed in the US prior to 1950 had a local advantage due to the availability of cheap local power (CLP). He further argues that this advantage disappeared after 1950, when the expansion of the electricity grid made transportation of electricity across large distances possible. His hypothesis is that locations that received hydroelectricity plants prior to 1950 will enjoy a positive short run effect due to the CLP advantage, while no such advantage will be found for locations where hydroelectricity plants were opened post 1950. Severnini (2014) uses population density as a measure of economic activity. By looking at the post-1950 development in the counties receiving hydroelectricity plants at an early stage, his hypothesis is that if the growth rate in population density persists even after the CLP advantage is removed in 1950, it is an indication of the presence of agglomeration effects. Using synthetic control methods and an event study research design, he finds that on average, locations with early hydroelectricity plants received significant short- and long run effects from the plant. Furthermore, he found no such effects for locations having hydroelectricity installed at later stages. It is however noteworthy that although there were short- and long run effects on average, the analysis also found examples of counties where there were no effect irrespective of the time scope.

We want to conduct a similar analysis to Severnini (2014), but studying Norwegian municipalities rather than American counties. Norway is well suited for such an analysis for several reasons. First of all, there are numerous hydroelectricity plants to study, as 96.1 percent of the electricity produced in Norway comes from hydroelectricity plants (Holstad and Henriksen 2015). Furthermore, many of these electricity plants were installed at an early date, making it likely that they caused similar CLP effects to the plants studied by Severnini (2014). Because the hydroelectricity plants are in remote areas, it is also possible to study the effects on the surrounding area without having other effects disturb the findings.

3 Theoretical Framework

In order to derive an analytical framework for analyzing agglomeration effects, it is important to understand the mechanisms behind economic agglomeration. As a result of this, we begin by presenting three possible explanations for the phenomenon of agglomeration effects, as outlined in Greenstone, Hornbeck, and Moretti (2010).

The first possible explanation is that being part of a large labor market is positive. The reasoning behind this is that having many firms and workers in the same labor market makes employment transitions more efficient for both firms and workers. The second argument is that transportation costs are lower if firms are located in densely populated areas. This is due to the higher number of customers and suppliers in the area as well as shorter transportation distances. The third argument is that firms benefit from location close to other firms due to knowledge spillovers. The interaction between firms and their employees is assumed to possibly yield an exchange of information between them that makes all the firms more productive.

These are three general reasons why agglomeration effects might occur, and in the next section we will present an analytical model specifically designed to explain why hydroelectricity plants may lead to agglomeration effects.

3.1 Analytical Model

The model is based on the framework presented in Severnini (2014), which is derived from Greenstone, Hornbeck, and Moretti (2010). The framework is suited for providing an understanding of why installation of hydroelectric plants may have made some Norwegian municipalities attractive for manufacturing firms.

First, assume that all firms produce goods using labor (L), capital (K), land (T) and electricity (E). Further assume that goods are nationally traded at a price equal to one. Lastly assume that there is a productivity shifter (A) that affects all inputs equally. The firm's optimization problem can then be written as:

$$\max_{L,K,T,E} f(A, L, K, T, E) - wL - rK - qT - sE \tag{3.1}$$

Where wage (w), price of capital (r), rent (q) and electricity price (s) are input prices. A includes all factors that affect the productivity of the inputs equally. This means that if agglomeration effects exist they will be included in A. To allow for this we assume that A is a function of population (N):

$$A = A(N) \tag{3.2}$$

If agglomeration effects exist, A will be a positive function of population (N):

$$\frac{\partial A}{\partial N} > 0 \tag{3.3}$$

$L^*(w, r, q, s)$, $K^*(w, r, q, s)$, $T^*(w, r, q, s)$ and $E^*(w, r, q, s)$ are defined as the optimal levels of labor, capital, land and electricity used by the firm given the factor prices in equilibrium.

Like Severnini (2014), we assume that capital (K) is internationally traded, so that its price r does not depend on local demand and supply conditions. However, wage w and rent q does depend on local conditions:

$$\begin{aligned} w &= w(N) \\ q &= q(N) \end{aligned} \tag{3.4}$$

Where we assume that:

$$\begin{aligned} \frac{\partial w}{\partial N} &> 0 \\ \frac{\partial q}{\partial N} &> 0 \end{aligned} \tag{3.5}$$

Assuming that the supply of labor and land is less than infinitely elastic at the municipality level, $w(N)$ represents the inverse of the reduced form supply function linking the population in a municipality to the local wage level. More specifically, this means that if the demand for labor increases in a municipality after a hydroelectricity plant is opened, the wages will increase, but the size of the wage increase depends on the propensity of workers from other municipalities to relocate. Similarly, the price of land depends on how easy it is to supply more land in the municipality. Therefore, $q(N)$ represents the inverse of the reduced form land-supply function. Given these assumptions, equilibrium profits, Π^* can be written as:

$$\begin{aligned} \Pi^* =& f[A(N), L^*(w(N), r, q(N), s), K^*(w(N), r, q(N), s), \\ & T^*(w(N), r, q(N), s), E^*(w(N), r, q(N), s)] - \\ & w(N)L^*(w(N), r, q(N), s) - rK^*(w(N), r, q(N), s) - \\ & q(N)T^*(w(N), r, q(N), s) - sE^*(w(N), r, q(N), s) \end{aligned} \tag{3.6}$$

We see that the productivity shifter (A), wage (w) and rent (q) depend on the population (N) in the municipality. Taking the total derivatives of profits with respect to the electricity price and population (s and N) gives us the following first order equations:

$$\begin{aligned}\frac{d\Pi^*}{ds} =& \frac{\partial L^*}{\partial s}\left(\frac{\partial f}{\partial L} - w\right) + \frac{\partial K^*}{\partial s}\left(\frac{\partial f}{\partial K} - r\right) + \\ & \frac{\partial T^*}{\partial s}\left(\frac{\partial f}{\partial T} - q\right) + \frac{\partial E^*}{\partial s}\left(\frac{\partial f}{\partial E} - s\right) - E^*\end{aligned} \tag{3.7}$$

$$\begin{aligned}\frac{d\Pi^*}{dN} = & \left(\frac{\partial f}{\partial A} * \frac{\partial A}{\partial N}\right) - \left(\frac{\partial w}{\partial N} * L^*\right) - \left(\frac{\partial q}{\partial N} * T^*\right) + \\ & \frac{\partial w}{\partial N}\left[\frac{\partial L^*}{\partial w}\left(\frac{\partial f}{\partial L} - w\right) + \frac{\partial K^*}{\partial w}\left(\frac{\partial f}{\partial K} - r\right) + \frac{\partial T^*}{\partial w}\left(\frac{\partial f}{\partial T} - q\right) + \right. \\ & \left. \frac{\partial E^*}{\partial w}\left(\frac{\partial f}{\partial E} - s\right)\right] + \frac{\partial q}{\partial N}\left[\frac{\partial L^*}{\partial q}\left(\frac{\partial f}{\partial L} - w\right) + \frac{\partial K^*}{\partial q}\left(\frac{\partial f}{\partial K} - r\right) + \right. \\ & \left. \frac{\partial T^*}{\partial q}\left(\frac{\partial f}{\partial T} - q\right) + \frac{\partial E^*}{\partial q}\left(\frac{\partial f}{\partial E} - s\right)\right]\end{aligned} \tag{3.8}$$

If we then assume that all firms are price takers and that all factors are paid their marginal product, most of the expressions in the parentheses cancel out and the equations simplify to:

$$\frac{d\Pi^*}{ds} = -E^* < 0 \tag{3.9}$$

and

$$\frac{d\Pi^*}{dN} = \left(\frac{\partial f}{\partial A} * \frac{\partial A}{\partial N}\right) - \left[\left(\frac{\partial w}{\partial N} * L^*\right) + \left(\frac{\partial q}{\partial N} * T^*\right)\right] \tag{3.10}$$

Where Equation 3.9 is an example of Hotelling's lemma, and implies that a firms profits are higher if the electricity price in the municipality is lower. This implies that if the construction of a hydroelectricity plant leads to lower electricity prices in a municipality (what Severnini (2014) refers to as a CLP advantage), it will make it more desirable for firms to operate there.

Equation 3.10 states that the effect of an increase in population on the firm's profits is the sum of two opposite effects. The first term, $\left(\frac{\partial f}{\partial A} * \frac{\partial A}{\partial N}\right)$ implies that profits increase if there are agglomeration effects $\left(\frac{\partial A}{\partial N} > 0\right)$, while the second term, $\left[\left(\frac{\partial w}{\partial N} * L^*\right) + \left(\frac{\partial q}{\partial N} * T^*\right)\right]$, states that profits decrease due to increases in wages and rents. The reasoning behind the second term is that increased population density and economic activity will result in higher demand for labor and land, thereby increasing wages and rents. The equation implies that if construction of hydroelectricity plants leads to higher population density in an area and there are significant agglomeration effects, we would expect the economy in the municipality to grow more than the reduced electricity price on its own would imply. Furthermore, this growth may continue even after the CLP effect disappears as long as the agglomeration effects are large enough.

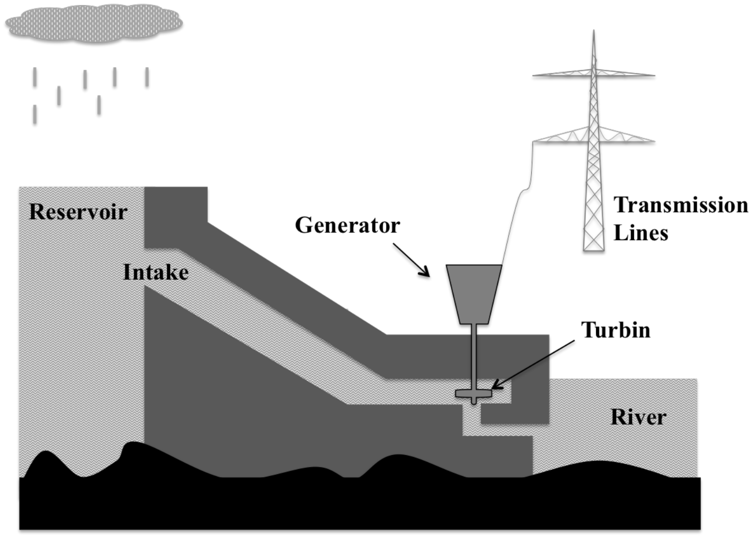
4 Hydroelectricity in Norway

Norway is located in northern Europe and consists of 428 municipalities distributed over 19 counties. Norway's topography and climate with mountains and large amounts of rainfall, especially in the coastal parts, makes the country very well suited for hydroelectricity generation (Rosvold 2010). This is because hydroelectricity plants use the energy from falling water to generate electricity, as illustrated in Figure 1.

4.1 Electrification

The potential for hydroelectricity in Norway was discovered early, and the first hydroelectricity plant (which was also the first one in Europe) was opened in 1882. While the first plant only supplied electricity to a manufacturing plant, a plant also supplying electricity for private consumers was opened in 1885 (Norwegian Water Resources and Energy Directorate 2013).

Figure 1: Illustration of Hydroelectricity Plant



Note: The figure illustrates the basics of how hydroelectricity plants function. Water is stored in the reservoir, then flows down the intake and spins the turbine, causing electricity to be generated.

These plants were quite simple technologically speaking, and in the following years there was a debate in the country regarding what was the best way of utilizing and transporting the energy provided by the water. A number of solutions were proposed, including using the physical force of the water to power "water engines" instead of generating electricity. In the end, it was decided that the best solution was to generate electricity at hydroelectricity plants and then transport the electricity to central stations near the consumers. The electricity would then be distributed to the consumers from the central stations. The first town to utilize this solution was Hammerfest, where they started using electricity for lighting in 1891 (Norwegian Water Resources and Energy Directorate 2013).

The 1890s was the period when the electrification of Norwegian cities gained momentum, and by the turn of the century, 20 cities were electrified to some degree, although the primary use of the electricity was lighting. In this period, the government did not see it as their responsibility to supply the manufacturing sector with electricity, meaning that although a number of cities were electrified, this did not mean that the manufacturing sector got access to electricity (Bøeng and Holstad 2013). Consequently, the manufacturing sector primarily generated its own electricity prior to the mid-1950s.

In the early stages of the electrification, there was a large degree of foreign investors involved in the projects, partly due to the fact that Norwegian banks and businesses did not have the funds necessary for the large investments required to construct the hydroelectricity plants. This resulted in a fear that the foreign investors were planning to acquire all the hydroelectricity resources and use them for their own personal gains. As a response to this, the government enacted what was to be known as the "panic law" in 1906. The law stated that no foreign citizens were allowed to acquire rights to waterfalls without approval from the Norwegian king. In the following years, the government ensured that local municipalities got authority regarding the development of hydro resources in their area. The municipalities were also secured a substantial part of the values that the developments resulted in (Norwegian Water Resources and Energy Directorate 2013).

Because the "panic law" was enacted very quickly, there was a significant debate in the following years regarding the best way to regulate the hydro resources. These discussions finally resulted in two concession laws in 1917 (Norwegian Water Resources and Energy Directorate 2013), which are largely the same laws as the ones that apply today. The elements of the laws most relevant for our thesis were that the national and local authorities had priority regarding acquisition, development and regulation of hydro resources. This also entailed a priority of supplying electricity to regular consumers over the manufacturing industry.

In this period, the hydroelectricity plants built kept increasing in size. Examples include the plants in Odda, Høyanger, Sauda and Rjukan. In fact, the plant in Rjukan was the largest in the world when it was opened in 1911 (Rosvold 2013). Such plants were found interesting enough to be mentioned in Popular Science Monthly, stating that "...water power is thus Norway's greatest natural resource" (Howe 1912, p. 42). These plants provided enough electricity to cover the demands of large manufacturing plants. As a consequence of this, such hydroelectricity plants laid the foundations for a number of manufacturing cities across Norway.

Large scale developments and good economic times in general caused Norwegian municipalities to make ambitious plans regarding the continued development of hydroelectricity plants. However, the economic climate changed in the 1920s and demand for electricity and manufactured goods started to decline (Norwegian Water Resources and Energy Directorate 2013). Consequently, several projects had to be put on hold due to strained finances in the local municipalities and the government. Some projects were however carried out in this period as well.

From the mid-1930s, the demand for electricity started to increase again, partly due to increased demand for aluminum to be used in the production in the arms industry. This also ensured that the construction of hydroelectricity plants continued despite the German invasion of Norway in 1940. In fact, the Germans left behind several partly finished hydroelectricity plants at the end of the war (Sejersted 2014).

With the end of the war also came a change in the government's involvement in the hydroelectricity sector. As a part of an extensive plan to rebuild the country, the government now took an active role in constructing hydroelectricity plants to supply power consuming manufacturing plants and private households with electricity. This resulted in a range of large-scale constructions such as the Aura power plant in Sunndal, which was opened in 1953. This development continued until the start of the 1960s, when most of the country was supplied with electricity. While the construction of hydroelectricity plants continued also after the 1960s, arguments concerning environmental factors played a much larger role in the later stages of the development. Such concerns include the desire to leave nature untouched as well as negative impacts on the river eco systems following changes in river levels and flow (Forsund 2007, p. 18).

An interesting aspect related to electricity consumption in this period is that electricity consumption per capita was significantly higher in several of the less densely populated counties than in the counties containing the major cities (this can be seen in Table 1). This indicates that there was an abundance of electricity in some rural parts of the country, which supports the argument regarding CLP outlined in the theoretical framework.

Table 1: Electricity Consumption per Capita

County	1937	1940	1947	1955
Østfold	3797	3971	5138	7531
Akershus	1951	2197	2907	3333
Oslo	1819	1914	2829	4152
Hedmark	601	587	1013	2236
Oppland	937	1058	1669	3384
Buskerud	3872	3214	4155	7672
Vestfold	1728	1526	2151	3676
Telemark	20160	19146	18247	29687
Aust-Agder	4407	4456	4709	7473
Vest-Agder	4168	4041	4218	7849
Rogaland	2890	2425	3078	5191
Hordaland	4832	4573	5783	7150
Bergen	1025	1058	1981	2950
Sogn og Fjordane	2644	3598	4369	11777
Møre og Romsdal	464	645	836	3261
Sør-Trøndelag	1069	1109	1653	2822
Nord-Trøndelag	2107	2486	2913	4178
Nordland	1259	1335	1060	5120
Troms	270	321	427	1026
Finnmark	802	588	222	1604
Country average	2856	2838	3340	5753

Note: The table shows electricity consumption per capita in kWh for selected years between 1937 and 1955.
Sources: Statistics Norway (1958, p. 11), Statistics Norway (1949, p. 20), Statistics Norway (1944, p. 11), Statistics Norway (1952, p. 15)

4.2 Electricity Grid

While Norway's topography and climate makes it very well suited for hydroelectricity generation, it also makes the transportation of electricity very challenging. Because transportation of electricity is a key component in the research design of the thesis, a summary of the development of the electricity grid is necessary.

The invention of alternating current (AC) electricity made transportation of electricity over significant distances possible even before 1900. An example of this is a transmission line from Lauffen to Frankfurt in Germany, which opened in 1891 and spanned 175 km. The first Norwegian transmission line remotely close to that was opened in 1903 and spanned the 84 km between Askim and Røyken (Riibe and Weyergang-Nilsen 2010). This transmission line was however located in the east of Norway, which meant that it was built in an area without mountains, making the construction considerably easier.

Constructing a transmission line in mountainous areas with snowy winters would prove more challenging. The first attempt at this was a transmission line between Rjukan and Oslo. Construction began in 1921 and transmission began in 1922. While the transmission line was completed, it turned out that it was not able to handle the tough winter conditions in the area, resulting in frequent transmission problems. However, during the following years, the engineers at the Norwegian Water Resources and Energy Directorate (NVE) became increasingly skilled at designing transmission lines that were able to withstand the Norwegian winters.

As the electricity grid kept expanding, especially in the eastern part of Norway, it soon became possible to connect increasing numbers of power stations and consumers to the same electricity grid. The advantage of this is that it allows for coordination of production from the different power stations, making the electricity market less vulnerable to demand peaks, rainfall shortages etc. (Riibe and Weyergang-Nilsen 2010). As a result of this, a group of electricity suppliers in the eastern part of Norway formed an organization with the goal of coordinating electricity production in 1932. An important reason why this happened in the eastern part of Norway first was that it is the most densely populated and least mountainous. This meant that the advantages of coordinating production were larger than the costs of expanding the electricity grid.

As the experience in constructing transmission lines and the demand for electricity grew further, it eventually became financially viable to expand the electricity grids in the rest of the country as well. This resulted in similar coordinating organizations as the one in the eastern part of the country. First came an organization in the mid of the country in 1953, then one in the area consisting of Sogn og Fjordane and Møre og Romsdal counties in 1955, then one in the north in 1960 and finally one in the Hordaland and Rogaland area in 1961. During the 1960s, transmission lines were also constructed between these coordinating areas, which eventually resulted in countrywide coordination in 1971 (Riibe and Weyergang-Nilsen 2010).

Like Severnini (2014), this thesis requires that we set a date when transportation of electricity over long distances was possible. This is somewhat challenging in Norway due to the fact that the pace of the expansion of the electricity grid differed between regions. Table 2 shows the share of the population in all counties that was provided with electricity between 1937 and 1955. The table shows that prior to 1955, the electrification degree in most western and northern counties was below 70 percent. Additionally, because the cities were electrified first, it is likely that the share of the population with electricity in the most rural parts of Norway was considerably lower than the county averages. Thus, we argue that because all counties in our dataset have an electrification degree above 80 percent in 1955, this seems like a reasonable year to set the end of the CLP advantage. This date is five years later than the date set by Severnini (2014), which is not unreasonable given the challenges posed by mountainous terrain and cold winters in Norway.

Table 2: Share of Population With Electricity

County	1937	1940	1947	1955
Østfold	97	97	94	99
Akershus	100	100	99	100
Oslo	100	100	100	100
Hedmark	73	78	85	96
Oppland	79	81	93	99
Buskerud	90	90	92	99
Vestfold	100	99	97	100
Telemark	85	85	93	99
Aust-Agder	76	81	80	98
Vest-Agder	90	91	90	98
Rogaland	80	79	83	96
Hordaland	59	61	65	98
Bergen	100	100	100	100
Sogn og Fjordane	39	46	61	95
Møre og Romsdal	55	58	64	97
Sør-Trøndelag	64	65	72	94
Nord-Trøndelag	56	66	77	92
Nordland	30	35	44	82
Troms	36	40	42	81
Finnmark	28	33	38	72
Country average	75	77	81	96

Note: The table shows the share of population supplied with electricity for selected years between 1937 and 1955.
Sources: Statistics Norway (1958, p. 11), Statistics Norway (1949, p. 20), Statistics Norway (1944, p. 11), Statistics Norway (1952, p. 15)

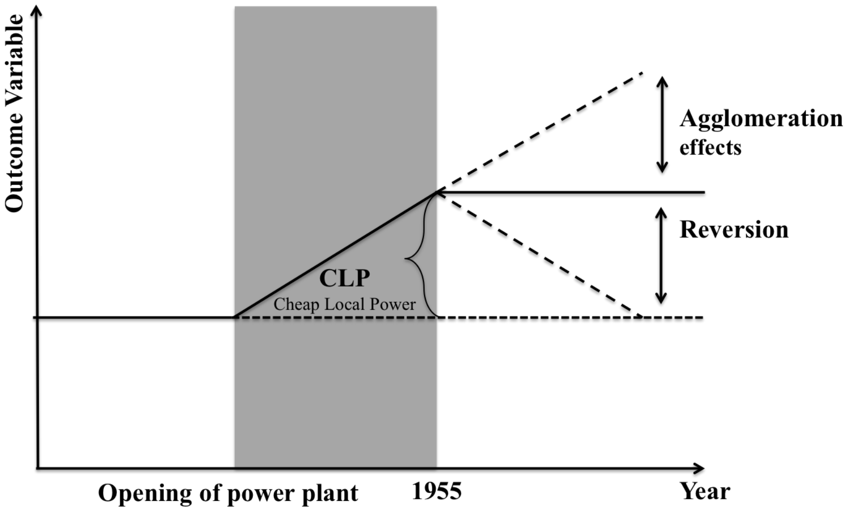
5 Methodological Approach

One way of analyzing agglomeration effects used in the literature is to analyze places that are exposed to shocks leading to increased economic activity and population, and then comparing them to places not experiencing the same type of shock. The theoretical framework indicates that the construction of hydroelectricity plants may have resulted in such shocks, and this is supported by Table 1. The table shows that in the years prior to 1955, electricity consumption per capita was significantly higher in several of the more rural counties than in the counties containing the major cities. The prime example is Telemark, where the electricity consumption per capita was more than ten times as high as in the capitol, Oslo, in 1937. The argument is further supported by the fact that Telemark had a lower electrification degree than Oslo (85 percent compared to 100), as seen in Table 2. This further implies that municipalities with early hydroelectricity plants may have become more attractive for manufacturing firms and experienced growth in population and economic activity. It is however important to note that such an increase is due to the availability of a natural advantage and not agglomeration effects. Our analysis will attempt to estimate and separate the effects caused by CLP and agglomeration. A central point in our research design is that once it becomes possible to transport electricity over large distances, the CLP advantage disappears. By looking at what happens to the economic activity after the natural advantage disappears, we will be able to identify whether there are agglomeration effects or not. This approach has the advantage that it handles the reverse causality issue mentioned in section 1. A key issue in such an analysis is that it is important to make sure that any observed differences are a result of the shock and not other factors, such as topography and other natural advantages. This means that an important point in our analysis has to be to identify valid comparison groups for the municipalities that had hydroelectricity installed early.

Severnini (2014) handles this by comparing US counties with hydroelectricity to counties without hydroelectricity, but with similar potential for hydroelectricity. Data on the hydroelectricity potential in each municipality is however not publicly available for Norway. Instead, we argue that the effect of a power plant on municipalities is different for plants opened before and after transportation of electricity over large distances was possible. This is because the electricity produced by plants constructed after 1955 can be transported away from the local municipality, implying that there will be no CLP advantage. Consequently, hydroelectricity plants installed after 1955 should not provide the same type of shock to population and economic activity. This argument is supported by the fact that there does not appear to be any shocks to population density after 1955 in the control municipalities (see Figure A13 in the appendix). Given that the municipalities in the dataset are similar with respect to distance to major cities, topography, population etc., the municipalities with hydroelectricity plants opened after 1955 appear to be good comparison groups. Hence, we compare municipalities with a hydroelectricity plant opened before 1955 to municipalities where a plant was opened after 1955. We also have data on the plants' production capacity in MW and therefore a measure of exploited hydroelectricity potential, allowing us to compare municipalities with similar potential for electricity generation.

Figure 2 illustrates our research design. As previously mentioned, we expect an increase in population density and economic activity following the opening of hydroelectricity plants due to the CLP effects. If the growth continues after the CLP advantage disappears, it is reasonable to assume that agglomeration effects are the reason. If however, the growth stagnates it is more likely that the natural advantage gave a permanent increase in economic activity (possibly due to sunk investments), but no extra effect in the form of agglomeration effects. If the municipality experiences a decline in economic activity when the natural advantage disappears, it is an indication that the natural advantage gave a temporary increase in economic activity, but that the increase was merely due to the natural advantage and disappeared along with it. We believe that a good starting point for our analysis is to follow Severnini (2014) and use the synthetic control method to estimate both the short run CLP effects and potential long run agglomeration effects.

Figure 2: Illustration of Empirical Approach



Note: The figure illustrates our empirical approach. The shaded area shows the period where the municipality has a cheap local power advantage. The development after the CLP advantage disappears (1955) shows whether there are agglomeration effects or not. The outcome variable is either log population density or log taxable income per tax payer.

5.1 Synthetic Control Method

The synthetic control method is a data driven procedure that can be used to construct a "synthetic" control municipality to be used as a comparison group. This is done by using a weighted average from a donor pool of potential control municipalities to obtain a municipality that matches the pre-treatment development of the treated municipality (see Abadie and Gardeazabal 2003; Abadie, Diamond, and Hainmueller 2010; Abadie, Diamond, and Hainmueller 2015). The synthetic control method is useful in cases where there is no obvious control group for the units of interest. An example of such a case can be found in Abadie and Gardeazabal (2003). The authors use the synthetic control method to construct a synthetic Basque country to study the effects of terrorist attacks in the area. The reason why they use the synthetic control method is that there are no other regions in Spain that can be convincingly used as a control group for Basque country. Our motivation for using the synthetic control method in this thesis is similar, as it may be difficult to find good comparison municipalities for the individual treated municipalities, but much more likely that it is possible to construct good synthetic control municipalities.

Formally, the procedure seeks to minimize:

$$||X_1 - X_0W||_V = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)} \tag{5.1}$$

Where X_1 is a $(K * 1)$ vector of pre-treatment values of K economic predictors in the treated municipality. These are the values that the procedure aims to match. X_0 is a $(K * J)$ matrix that contains the values of the same variables for a donor pool of J possible control municipalities. V is a diagonal matrix with nonnegative components. $W = (w_1, ..., w_J)'$ is a $(J * 1)$ vector of nonnegative weights that sum to one. The scalar $w_j (j = 1, ..., J)$ represents the weight of each unit in the synthetic control municipality. W^* is set to minimize the difference between pre-treatment values in the treated unit and its synthetic control unit (Abadie and Gardeazabal 2003). The post treatment difference between the treated municipality and its synthetic control is then given by:

$$Y_{1,t} - \sum_{j=2}^{J+1} w_j^* Y_{j,t} \tag{5.2}$$

Where $Y_{1,t}$ is the actual post treatment values in the treated municipality at time t and $\sum_{j=2}^{J+1} w_j^* Y_{j,t}$ is the corresponding value in the synthetic control municipality. This difference is used to obtain statistical inference.

While the synthetic control method is suited for finding valid control groups, it requires a specific approach to obtaining inference as there is no way of obtaining valid standard errors when using the procedure. We use the approach proposed in Abadie, Diamond, and Hainmueller (2010). They propose using what they call a "placebo study". The placebo study starts by computing synthetic counterfactuals for all the municipalities in the donor pool using the opening date of the hydroelectricity plant in the treated municipality as the treatment date for all municipalities. We then calculate the difference between the actual observations and the outcomes predicted by the synthetic counterfactual. By comparing how large the differences between the actual and predicted observations are in the treated municipality relative to in the placebo studies, we get an impression of whether treatment actually has an effect or not. If treatment has an effect, the difference should be significantly larger in the actual treated municipality than in the placebo studies.

A second issue related to the synthetic control method is that it requires strictly balanced panel datasets. The reason for this is that it needs data from all municipalities used to create the synthetic control municipality at all points in time to be able to compute a consistent synthetic control municipality. To handle this we either have to exclude municipalities with missing data points from the donor pool, or restrict the analysis to only include data points without missing values for any municipality.

A further issue is that it is desirable to compare municipalities that are similar with respect to other economic predictors than the outcome variable as well. Following Severnini (2014), we therefore specify that the size of the turbine installed in the hydroelectricity plant, what part of the country the municipality is located in and average yearly precipitation should be used as predictors for the outcome variable when computing the synthetic control municipalities.

While Severnini (2014) only uses data on population density, we believe that it is possible that there may be agglomeration effects that are not observable when using population density as a measure of economic activity. One possibility is that the shock supplied by the CLP advantage also leads to productivity growth, as indicated in the theoretical framework, and that the productivity growth exhibits agglomeration effects even if the increase in population subsides when the CLP advantage disappears. Consequently, we will expand the analysis done in Severnini (2014) by also estimating agglomeration effects using taxable income per tax payer as the measure of economic activity. If there are agglomeration effects related to productivity growth, it is reasonable to assume that this will be observable when looking at taxable income as it is a common assumption in economics that productivity and wages are connected.

Expanding the analysis in this way has two advantages. Firstly, it may allow us to uncover agglomeration effects that are unobservable when looking at population density. Secondly, it will allow us to obtain a measure of the welfare effects of the hydroelectricity plants that analyzing population density does not provide. This is because an increase in population density does not necessarily imply increased welfare.

5.2 Rolling Out

Up to this point, the analysis focuses on individual municipalities. In addition to this, it would also be informative to obtain a quantitative measure of average effects with respect to both CLP and agglomeration. While suitable for analyzing individual municipalities, the synthetic control method is not suited for obtaining quantitative measures of the average effects in the dataset. We therefore employ the rolling out approach to obtain quantitative estimates. The rolling out approach allows us to utilize the variation in the data regarding the time and duration of treatment to estimate average effects across all treated municipalities. Some examples of papers utilizing this approach include Akerman, Gaarder, and Mogstad (2015) and Bhuller et al. (2013). The econometric model we are going to estimate is:

$$Y_{m,t} = \beta_0 + \beta_1 * CLP_{m,t} + \beta_2 * agglomeration_{m,t} + \gamma * year_t + \epsilon_{m,t} \tag{5.3}$$

where Y is the dependent variable (either log population density or log taxable income per tax payer) in municipality m at time t. β_0 is a constant term. CLP is a yearly trend after the opening of hydroelectricity plants. That is, CLP is equal to zero before the opening of a plant, takes the value one in the year of the opening, two in the year after the opening and so on. Hence, the estimated β_1 shows the effect of cheap local power after the plant establishment. *Agglomeration* is a yearly trend after it becomes possible to transport electricity across large distances (in 1955). That is, *agglomeration* is zero before 1955, one in 1955, two in 1956 and so on. This implies that β_2 is the estimated agglomeration effect. $Year$ is a vector of dummy variables for each year and ϵ is an error term. The year-dummies are included to control for yearly developments that are shared by all municipalities (e.g. country wide recessions and booms) and allow us to control for any common trends in the data.

The fact that our dataset has a panel structure presents some potential issues that needs to be addressed. Firstly, when estimating models on panel data it is possible that the error terms within each panel are correlated. If this is the case, the usual standard errors cannot be used for inference. This issue can be handled by estimating the models and specifying that the standard errors should be cluster robust. This approach will be incorporated into the analysis. A further issue is that there may be panel specific effects that are correlated with both our explanatory variables and the outcome variable, and failing to control for this is likely to lead to biased estimates. One way of handling this is to use the fixed effects estimator.

5.2.1 Fixed Effects

The fixed effects estimator can be used to handle problems caused by correlation between unobserved panel specific, time invariant effects and the explanatory variables in a model. If the unobserved effects are also correlated with the outcome variable it will lead to a bias in the estimates known as omitted variable bias. The fixed effects estimator handles this by removing all time invariant factors, including the unobserved ones, thereby eliminating the bias. A general example of how this is done formally is:

The initial model is:

$$y_{i,t} = \beta_0 + x'_{i,t}\beta + \alpha_i + u_{i,t} \tag{5.4}$$

where $y_{i,t}$ is the outcome variable, $x'_{i,t}$ is a vector of explanatory variables while $\alpha_i + u_{i,t}$ is an error term consisting of a panel specific and time invariant component (α_i) and a second term ($u_{i,t}$) which is assumed to be uncorrelated over time (Verbeek 2012). To remove the unobservable panel fixed effect α_i we transform the model by estimating it in terms of deviations from means (known as within transformation), this yields:

$$(y_{i,t} - \bar{y}_{i,t}) = (\beta_0 - \bar{\beta}_0) + \beta(x'_{i,t} - \bar{x}'_{i,t}) + (\alpha_i - \bar{\alpha}_i) + (u_{i,t} - \bar{u}_{i,t}) \tag{5.5}$$

From equation 5.5 we see that all time invariant factors, including the fixed effect, will be cancelled out of the equation because they are equal to their means, solving the problem with omitted variable bias. An example of such an unobservable fixed effect in our analysis is the geographical features of the municipalities. Such geographical features may be correlated with the outcome variables, meaning that failing to control for them may lead to biased estimates. Using the fixed effects estimator to control for such effects is therefore likely to yield more precise estimates in the analysis.

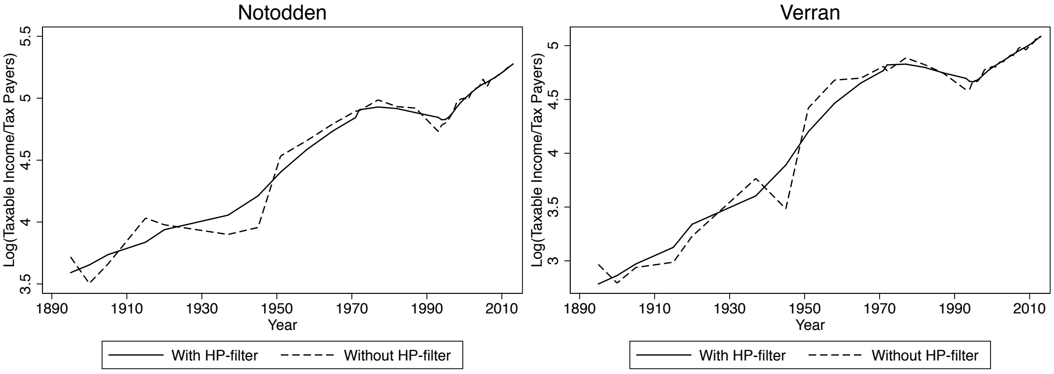
5.3 Hodrick-Prescott Filter

In parts of the analysis we will be using data on taxable income. These time series exhibit significant volatility, which may influence the results in the analysis. The reason is that short run fluctuations caused by business cycles may coincide with crucial dates in the analysis, which will potentially change our estimated effects. This is unfortunate because it is the long run development in income that is of interest and not short run fluctuations. One way of handling such problems, often used in the macroeconomic literature, is the Hodrick-Prescott (HP) filter. The HP filter is a method of smoothing time series to remove short run business cycle fluctuations and only be left with the long run trend. It is arguable that removing some of the short run volatility in the data will allow for more precise estimation. In macroeconomic research the filter is often used on variables such as GDP to obtain estimates of business cycle fluctuations. A discussion regarding the use of the HP filter to estimate business cycles can be found in Kydland and Prescott (1990). Because taxable income is likely to be correlated with GDP, using the HP filter to smooth our time series seems reasonable. Formally what the HP filter does is minimize the loss function:

$$\sum_{t=1}^{T}(y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1}[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2 \tag{5.6}$$

where τ_t is the estimated trend while y_t is the actual observations, both at time t. The first term states that the squared deviations between the estimated trend and the actual time series should be minimized. The second term states that the squared differences between the estimated trend at time t and the estimated trend at time $t+1$ and $t-1$ should be minimized. Minimizing the second term implies reducing the volatility of the series, so λ is a parameter to be set to achieve the desired level of volatility smoothing (Kydland and Prescott 1990). Using this approach will allow us to obtain less volatile time series of income data, which will allow us to obtain estimates of the long run development without them being disturbed by short run fluctuations. Figure 3 shows two examples of volatility smoothing using the HP filter.

Figure 3: Example of HP Filter



Note: The figure shows a comparison between log taxable income per tax payer with and without HP filtering for two municipalities. The smoothing parameter is set to 6.25 when applying the HP filter.

6 Data

Obtaining data for analyzing agglomeration effects following the construction of hydroelectricity plants is challenging for a number of reasons. It is necessary to obtain data on where hydroelectricity plants were constructed, when they were opened and ideally also some information on the size of the plants. The starting point was a dataset containing information on all hydroelectricity plants currently in operation that was provided to us by NVE. The dataset contained information on the location, year of opening and production capacity in MW for all plants. We expanded these data by digitalizing a report from NVE from 1946 containing all hydroelectricity plants in operation at that time (Norwegian Water Resources and Energy Directorate 1946). Expanding the dataset was necessary because only analyzing plants currently in operation might bias the results as these plants may be different from the ones that have been shut down. We further expanded the dataset by obtaining data on precipitation for all weather stations in all counties between 1945 and 1955 from the Norwegian Meteorological Institute (2015). This data is used to compute average yearly precipitation for all counties.

The analysis also requires a good measure of economic activity that is available at a sufficiently detailed level and observable in a consistent manner over a long period of time for any potential agglomeration effects to be observable. Following Severnini (2014), we collected data on population at the municipality level as a starting point. The necessary data for computing populations densities (population and area) was available in the Norwegian census data across the entire period of interest. The data from 1875 until 1946 was obtained by digitalizing census reports from Statistics Norway's archive of historical statistics[1]. The data from 1951 until 2013 was obtained in digitalized form from Statistics Norway (2015).

An issue with the data is that a number of municipalities have been affected by changes either by being merged with other municipalities or split into smaller municipalities as a result of political decisions (a detailed description of the changes can be found in Juvkam 1999). This means that for some municipalities, data from early years is not available, whereas for others there is no data available in later years. In particular, there were a number of changes in 1964 that needs to be addressed. In some cases, this is easily handled because the changes were so small that they had no practical implications. In other cases, it is reasonable to analyze the merged municipality because the municipality of interest still is of significant importance after the merger. In such cases we combine the populations in the municipalities forming the final municipality in the years before they were merged. There are also cases where the problem is that the municipality of interest was a result of a separation of a larger municipality, making data from early years unavailable. In some of those cases, we assume that the proportion of the population in the initial municipality was the same the entire time before the separation, and use that proportion of the original municipality in the analysis. However, this is only done in cases were we only lack a few points of data. Finally, there are some cases where there is no way of resolving the issues of merging or separation in a reasonable way and those municipalities are dropped from the analysis.

Furthermore, the mergers and separations caused changes in the area of the municipalities. In municipalities where there were only minor changes we assume that the area was constantly the same as it was in 1946. In municipalities where there were large changes around 1964, we assume that the area was constant at the level it was in 1970 (Statistics Norway 1974a). One last challenge is that some municipalities, especially in the northern part of the country, were severely affected by the Second World War. Analyzing what happened in the years after 1955 in such municipalities might compromise our results. Hence, a number of municipalities severely affected by the war are dropped from the analysis. Figure 4 shows the municipalities included in the dataset as well as

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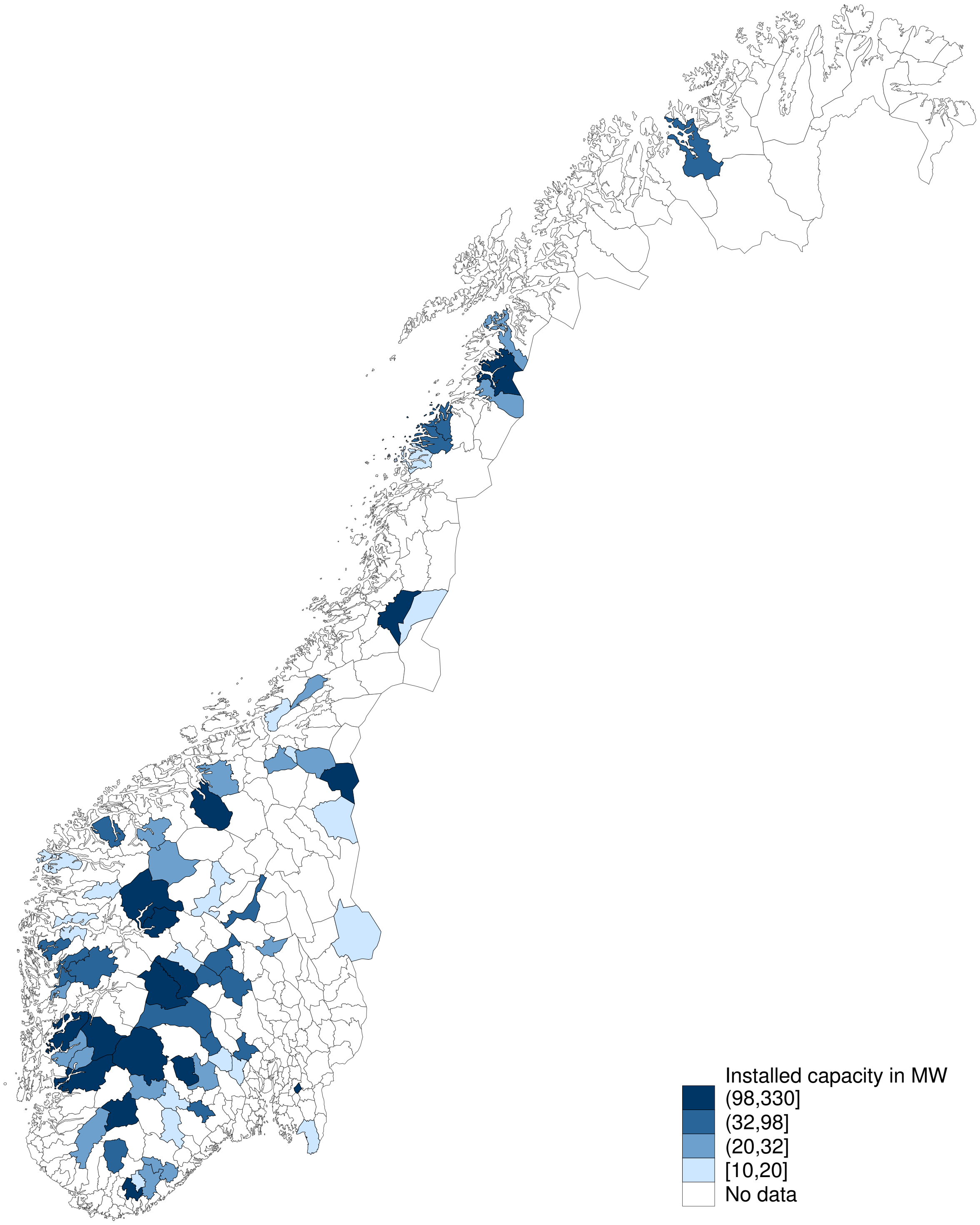
[1] Sources: Statistics Norway 1878; 1894; 1902; 1912; 1922; 1932; 1950

the production capacity of the hydroelectricity plant when it was opened.

Figure 4: Map of Hydroelectricity Plants in the Dataset



Note: The figure shows the municipalities in the dataset and the production capacity of the initial turbine installed in the hydroelectricity plant.

Sources: Kartverket (2014) and Sandvik (2013)

To obtain a second measure of economic activity, we also digitalized data on taxable income and the number of tax payers from Statistics Norway's archive of historical statistics[2]. An issue with this data is that the way it was reported by Statistics Norway varies somewhat over the period of interest. In order to obtain time series that are consistent across the time period we use taxable income per tax payer in the analysis, as this was most consistently reported. The tax data is then real price adjusted to real 1998 Norwegian kroner using consumer price index data from Statistics Norway (2014).

This unique dataset will allow us to contribute to the literature by conducting a similar analysis to Severnini (2014) in a different country, as well as expanding it with a different measure of economic activity. The dataset contains data from 67 municipalities and spans from 1875 until 2013. Summary statistics of the dataset are shown in Table 3.

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[2] Sources: Statistics Norway 1896; 1901; 1906; 1916; 1921; 1939; 1948; 1953; 1960; 1967; 1973; 1974j; 1974d; 1974i; 1974c; 1974q; 1974n; 1974b; 1974p; 1974k; 1974e; 1974l; 1974f; 1974m; 1974h; 1974g; 1974o; 1979i; 1979c; 1979h; 1979b; 1979p; 1979m; 1979a; 1979o; 1979j; 1979d; 1979k; 1979e; 1979l; 1979g; 1979f; 1979n; 1984i; 1984c; 1984h; 1984b; 1984p; 1984m; 1984a; 1984o; 1984j; 1984d; 1984k; 1984e; 1984l; 1984g; 1984f; 1984n; 1989i; 1989c; 1989h; 1989b; 1989p; 1989m; 1989a; 1989o; 1989j; 1989d; 1989k; 1989e; 1989l; 1989g; 1989f; 1989n; 2013a; 2013b

Table 3: Summary Statistics

	Count	Mean	Sd	Min	Max
Year	5082	1971.15	31.18	1876.00	2013.00
Startup Year	5082	1949.89	17.69	1907.00	1968.00
Capacity in MW	5082	74.30	81.56	10.00	330.00
Population	4716	5343.82	4693.08	392.00	29880.00
Area in Square KM	5082	1084.09	682.89	67.74	3106.00
Population Density	4716	9.44	21.49	0.25	226.09
Number of Tax Payers	2400	3571.02	3644.48	181.40	24029.00
Taxable Income	2400	486616.61	616558.80	4429.23	4602357.50
Precipitation	5082	1149.31	421.62	651.17	1937.03
East	5082	0.38	0.49	0.00	1.00
South	5082	0.10	0.30	0.00	1.00
West	5082	0.21	0.40	0.00	1.00
Mid	5082	0.21	0.40	0.00	1.00
North	5082	0.10	0.30	0.00	1.00
Observations	5082				

Note: The table shows summary statistics of the variables of interest. Count is number of observations. Mean is the average of values for each variable. Sd is the standard deviation. Min and Max is the interval representing the maximum and minimum values of each variable in the dataset. Startup year is the year the hydroelectricity plant was opened, capacity in MW is the production capacity of the initially installed turbines, number of tax payers is the registered number of tax payers in the municipality, taxable income is taxable income in 1000 real 1998 Norwegian kroner, precipitation is average yearly precipitation in mm in the county the municipality is located in. East, South, West, Mid and North are dummy variables for which region the municipality is located in.

Startup year is the year the hydroelectricity plant was opened, capacity in MW is the production capacity of the installed turbines, number of tax payers is the registered number of tax payers in the municipality, taxable income is taxable income in 1000 real 1998 Norwegian kroner, precipitation is average yearly precipitation in mm in the county the municipality is located in. East, South, West, Mid and North are dummy variables for which region the municipality is located in.

7 Case Studies

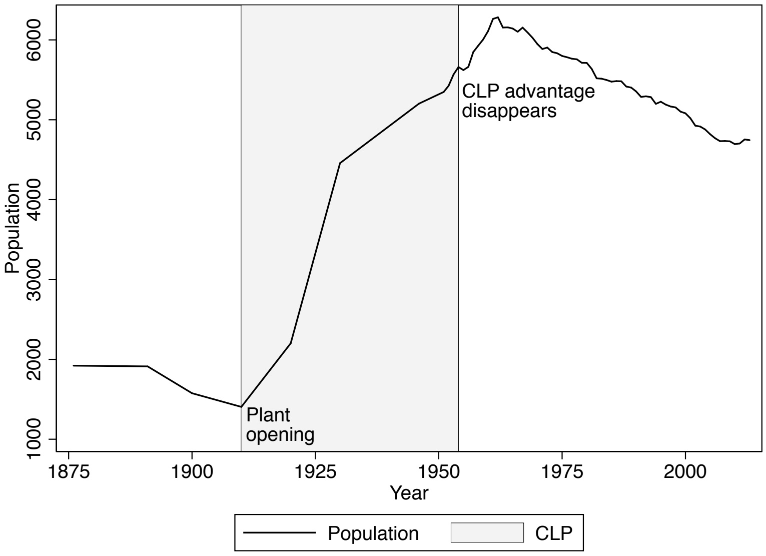
To illustrate the validity of the theoretical framework this thesis is based upon, we will present two case studies of municipalities where it seems clear that the opening of a hydroelectricity plant had a significant effect on economic activity and population.

7.1 Sauda

Sauda is located in the northern part of Rogaland county in the west of Norway. In 1913 a group of individuals formed a company aimed at utilizing the hydroelectricity potential in the Sauda area (Skagen 1977). After the company was formed, they focused on surveying the hydroelectricity potential in the area and trying to find a customer for the electricity they were going to produce. The work was successful, and on February 2^{nd} 1914, a contract was signed with the Union Carbon and Carbide Corporation, based in New York. Following the signing of the contract, construction of the hydroelectricity plant started. Electricity production started in 1919, and in 1923 production of manganese steel commenced at a metallurgy plant called Sauda smelteverk (Fløgstad 1990).

The plant was to become a cornerstone in the municipality and had a major impact on the small city. In 1920 the municipality had a population of 2201, and by 1930 this was more than doubled to 4457. The increase continued and in 1946 the population was 5202. The development in population can be seen in Figure 5.

Figure 5: Population in Sauda



Note: The figure shows the development in Sauda's population between 1876 and 2013. The grey area is the period when the municipality had a cheap local power advantage. Plant opening refers to the closest observation prior to the opening year of the hydroelectricity plant. The cheap local power advantage is assumed to disappear in 1955.

While the opening of the metallurgy plant seems to have lead to a significant increase in the municipality's population, it also had profound effects on the municipality's employment structure. In 1920 there were a total of 779 registered workers in the municipality, of which 154 (19.8 percent) were employed in the manufacturing sector (Skagen 1977). By 1946 the total number of workers had increased to 1968, of which 1248 (63.4 percent) were employed in the manufacturing sector. Between 1920 and 1946 the total population increased by 3001, the total number of registered workers increased by 1189, while the number of workers employed in the manufacturing sector increased by 1094. This indicates that the new jobs created by the opening of the metallurgy plant lead several families to move to Sauda, and that the vast majority of the workers who moved to Sauda started working in the manufacturing sector.

7.2 Odda

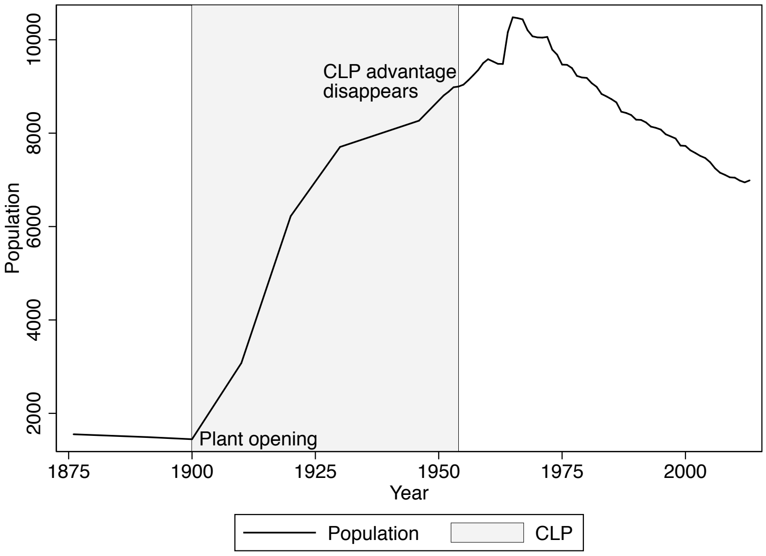
Odda is located in the southern part of Hordaland county in the west of Norway. In the 1820s and 1830s, the first foreign tourists started visiting Hardangerfjorden, and as communication got better and the establishment of local hotels offered tourists some sort of comfort, tourism started increasing. Located at the end of Hardangerfjorden, Odda became an ending point for boat traffic. Most of the visitors came from England, and Sigurd Ibsen wrote from his visit to Odda in 1877 that there were so many people from England there that English was more spoken than Norwegian (Andersen et al. 1989, p.25).

In the late 1890s people started seeing the potential of the large waterfalls in Odda, and in 1904, Alby United Carbide Factories and North Western Cyanamide Company started the planning and development of two manufacturing factories. They chose Odda because of its ice free harbors and the opportunity to use cheap local power. Following this, A/S Tyssefaldene started the construction of a hydroelectricity plant, which would provide the manufacturing industry with electricity.

The hydroelectricity plant was opened in 1908, which combined with the opening of the manufacturing factories had a major impact on the municipality's economy. Workplaces were generated, the income level increased and the small municipality was transformed into an industrial adventure. Approximately 70 million kroner was directly or indirectly invested in the manufacturing industry in Odda. In 1906 Odda was a small seaside resort with around 1500 inhabitants who lived off of tourist traffic and farming. At the census in 1920 the population in Odda was 6500, showing how major the impact of the manufacturing plants was. The development in population can be seen in Figure 6.

Odda was not directly affected by the First World War, but because labor wages, coal- and shipping prices escalated during the war, the factories were forced to close down at the end of 1920. Consequently, in 1921 the whole basis of existence for the young industrial society that had emerged in Odda broke down. However, production in the manufacturing sector was reopened in June 1924. Because of the cheap local electricity provided by the hydroelectricity plant, Odda was still a desirable place to have manufacturing. Even during the Second World War, the German invaders wanted the factories to maintain their production (Andersen et al. 1989), proving that Odda is a prime example of Norwegian manufacturing cities during the 1900s. However, the economic downturn in the 1920s also shows that relying heavily on energy intensive industries is not without risk.

Figure 6: Population in Odda



Note: The figure shows the development in Odda's population between 1876 and 2013. The grey area is the period when the municipality had a cheap local power advantage. Plant opening refers to the closest observation prior to the opening year of the hydroelectricity plant. The cheap local power advantage is assumed to disappear in 1955.

8 Empirical Analysis

The analysis consists of two parts. In the first part, we follow Severnini (2014) and estimate the effects of hydroelectricity plants using the synthetic control method. In the second part, we estimate average CLP- and agglomeration effects for the treated municipalities using the rolling out identification strategy and the fixed effects estimator.

8.1 Synthetic Control Method

In this part of the analysis, we analyze each of the treated municipalities separately using the synthetic control method to obtain counterfactuals. Both population density and taxable income per tax payer will be analyzed. The procedure begins by constructing the synthetic control municipalities for each of the municipalities we wish to analyze. The synthetic control municipalities are obtained by weighting a set of possible control municipalities to match the development in the outcome variable (either log population density or log taxable income per tax payer) in the treated municipality. Some papers applying the synthetic control method have chosen to include all pre-treatment observations of the outcome variable as predictors, which ensures a very good fit in the pre-treatment development of the actual and synthetic unit (see Billmerier and Nannicini 2013; Bohn, Lofstrom, and Raphael 2014; Liu 2015). However, there is a recent discussion in the literature on how to specify the synthetic control model. It has been pointed out that including all pre-treatment observations of the outcome variable as predictors will cause the weights placed on all other predictors to be zero. This is unfortunate because it is important for the validity of the synthetic control method that the synthetic control unit resembles the actual unit with respect to other economic predictors as well as the outcome variable. If this is not the case, the validity of the inference may be compromised (Kaul et al. 2015). To avoid this potential source of bias, we specify that average pre-treatment values as well as the value from the last pre-treatment observation of the outcome variable should be used to predict the values in the synthetic control municipality.

In addition to the outcome variable, we specify that the size of the turbine in the electricity plant, what part of the country the municipality is located in (east, south, west, mid or north) and average yearly precipitation in the county can be used as a predictors for population density. This differs somewhat from Severnini (2014), who also includes cubic functions of latitude and longitude as well as 50 year average temperatures. Our dataset does not contain data on latitude, longitude and temperatures, but we argue that including turbine size, region and precipitation is sufficient given that Norway is significantly smaller than the US.

After obtaining the synthetic counterfactuals, we proceed by using the placebo study procedure proposed in Abadie, Diamond, and Hainmueller (2010). We apply this procedure as there is no way of obtaining valid standard errors for statistical inference using the synthetic control method. The placebo study procedure starts by computing synthetic counterfactuals for all the municipalities in the donor pool using the opening date of the hydroelectricity plant in the treated municipality as the treatment date for all municipalities. We then calculate the difference between the actual observations and the outcomes predicted by the synthetic counterfactual. By comparing how large the differences between the actual and predicted observations are in the treated municipality relative to in the placebos, we get an impression of whether treatment actually has an effect or not. If treatment has an effect, the difference should be significantly larger in the actual treated municipality than in the placebos. Following Abadie, Diamond, and Hainmueller (2010) we also restrict the placebos we use in the comparison by calculating the mean squared prediction error (MSPE) prior to treatment and only use placebos where the MSPE is no more than twice as large as in the treated municipality. This is done to ensure that we do not use placebos where the synthetic control method has produced a poor counterfactual.

As mentioned in the methodology part, the research design predicts three possible outcomes with respect to agglomeration effects. The first one is that there are indeed *agglomeration effects*, in which case we will see a positive difference between the actual development in the municipality and its synthetic control after 1955. A second case is when the difference in the development between the actual and synthetic municipality is not significantly different from zero after 1955, which implies that there may have been an effect of having cheap local power, but *no agglomeration effects.* The last case is when the treated municipality develops negatively compared to the synthetic control, which implies that when the cheap local power advantage is removed, the effects of the cheap local power also vanish, i.e. *reversion.* Additionally, it is possible that there is no significant difference between the actual and synthetic municipality in the period where we expect CLP effects. When there is *no CLP effect* we do not expect to see any agglomeration effects. Because the implications of these four cases are very different, the results will be divided according to which case they fit best.

8.1.1 Population Density

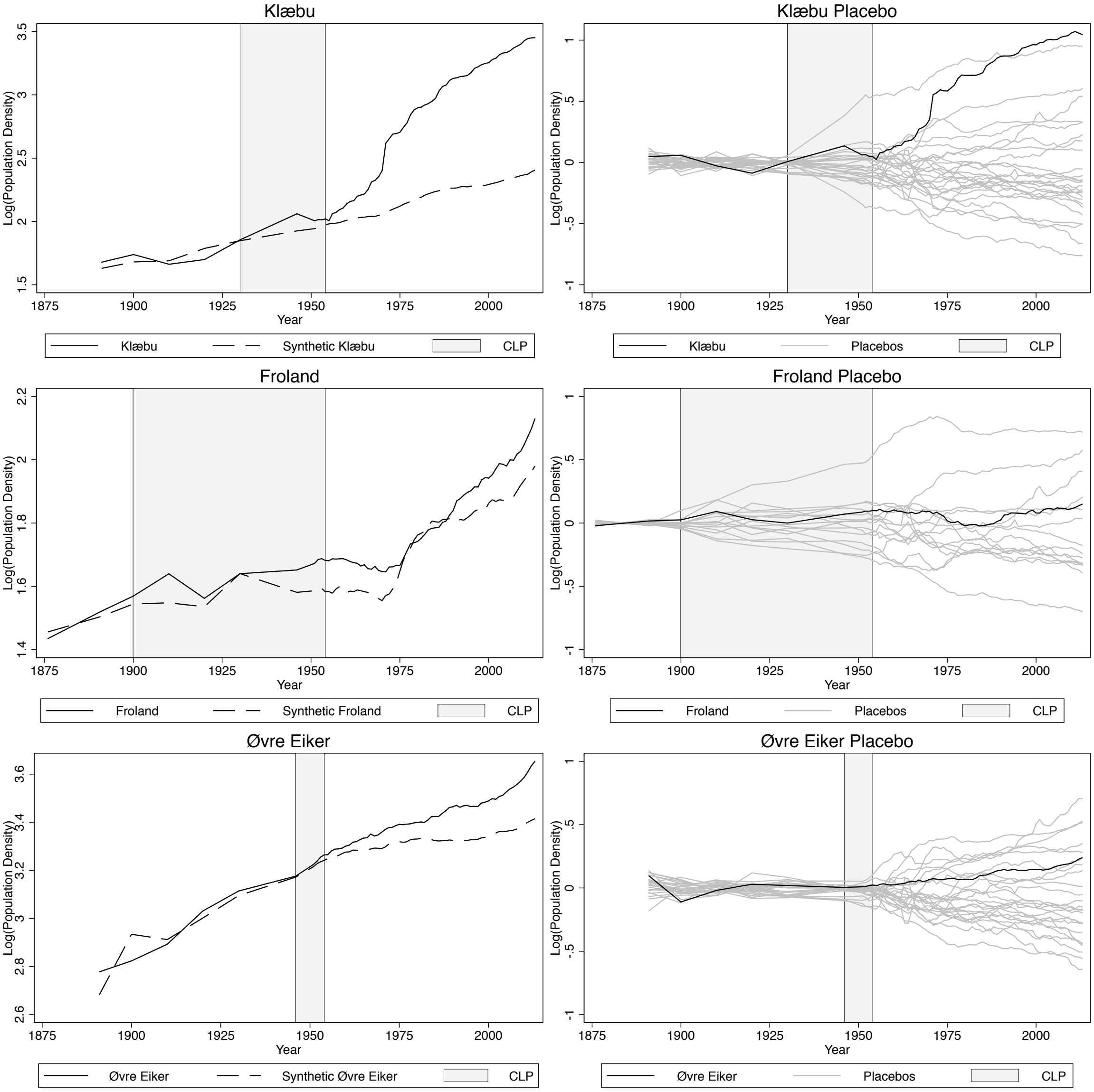
In this section, we will present the results of the synthetic control analysis when looking at population density. For presentational purposes we have selected a few municipalities fitting with each of the cases mentioned in the previous section to include in the main text while the rest can be found in the appendix (Figure A1-A6).

In the figures, the graphs on the left show the actual observations in the municipality (solid line) compared to the synthetic counterfactual municipality (dashed line). The figures on the right show the placebo studies, with the municipality being analyzed in black against the placebos in grey. The interpretation of the placebo studies is that if the actual municipality shows significantly more positive development relative to its counterfactual than the placebos, it is an indication of CLP- or agglomeration effects (depending on what period we are looking at).

No Cheap Local Power Effects

Figure 7 shows three municipalities where the analysis shows no indication of CLP effects. Most of the municipalities in the dataset belong in this category. There are however municipalities that arguably had CLP effects, but are not clear cut cases when looking at the placebo studies. In these cases we have chosen to be conservative and place them in the no CLP category. One possible explanation why there are no CLP effects is that the electricity produced by the electricity plant was used for other purposes than manufacturing. Additionally, the fact that the turbines installed in most of these municipalities are among the smaller ones in the data may be an explanation why there are no significant CLP effects. In any case, in the municipalities where there are no clear CLP effects, the theoretical framework implies that there are no agglomeration effects, so these municipalities are of no further interest in this part of the analysis.

Figure 7: No CLP

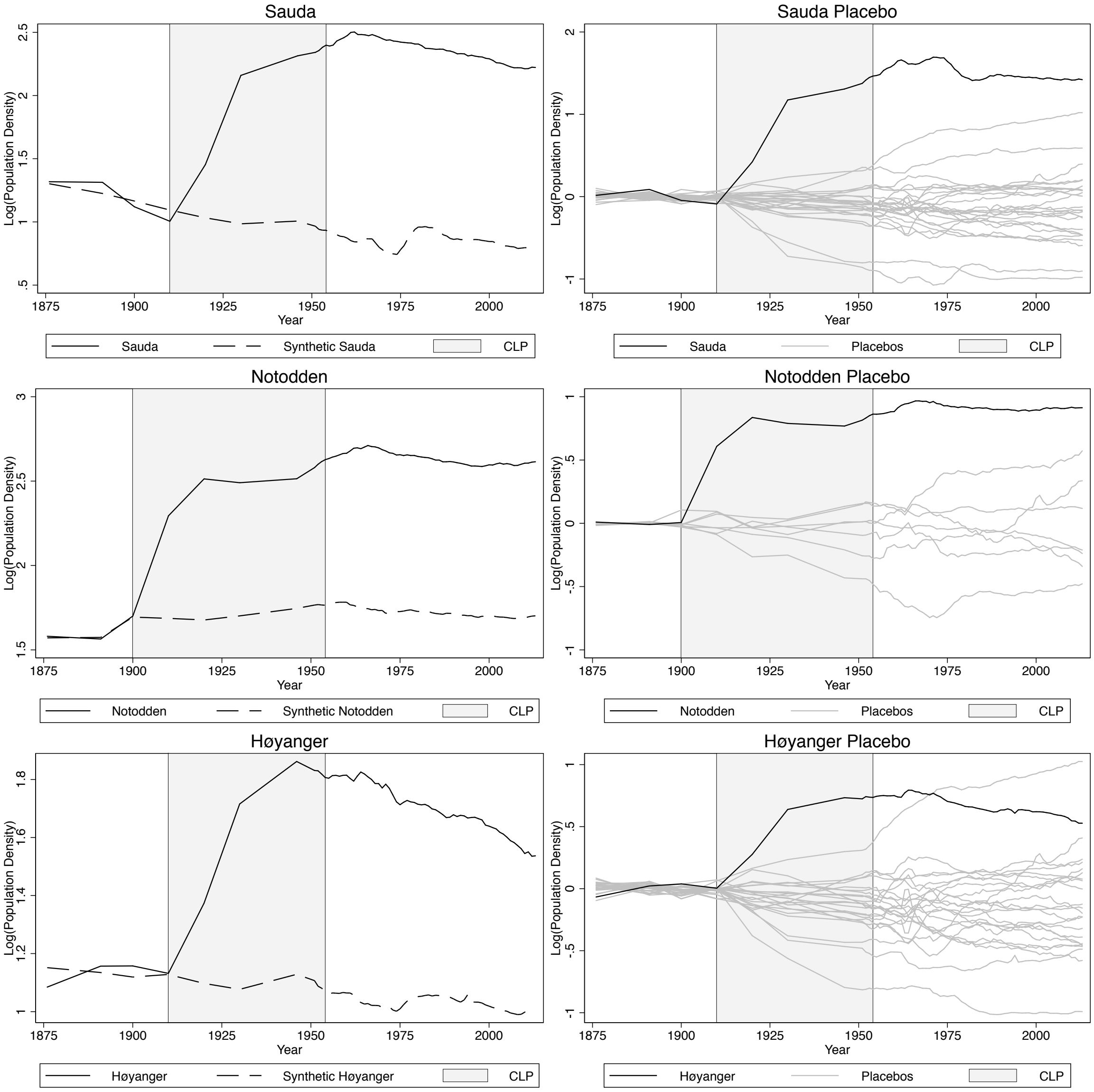


Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

No Agglomeration Effects

Figure 8 shows three municipalities where the analysis indicates that there were significant CLP effects, but no agglomeration effects. The graphs clearly indicate strong CLP effects, but we see that the growth subsides around the time transportation of electricity becomes possible. The finding of CLP effects seems reasonable for the three municipalities shown in the figure, as they are all typical Norwegian manufacturing municipalities in the 1900s. With respect to the period after 1955, the figures clearly show that the growth subsides, and when approaching the turn of the century, the growth is arguably slightly negative. A possible reason why the population density would remain constant at a higher level even after the CLP advantage disappeared, is that at that point, a large manufacturing industry had already been developed in the municipalities. This means that moving would be very expensive due to sunk investments, which is fitting in typical manufacturing municipalities.

Figure 8: No Agglomeration

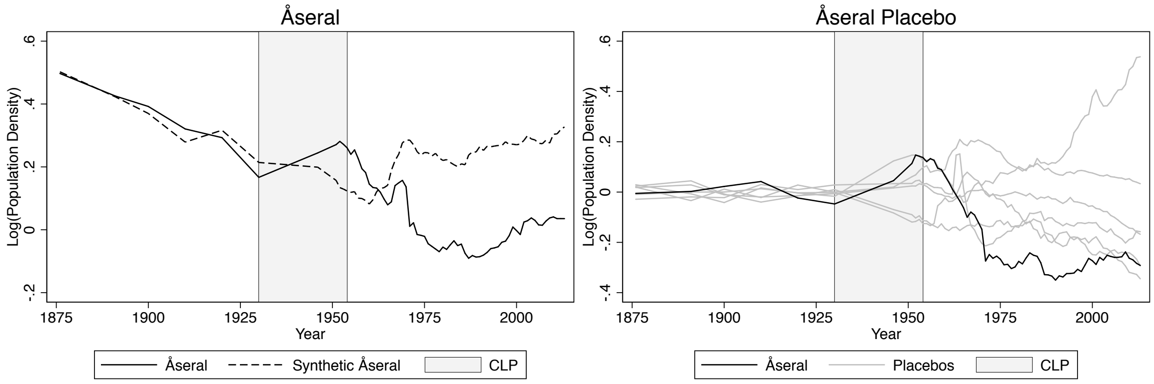


Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Reversion

Figure 9 shows the only municipality where the analysis indicates reversion. One reason why a municipality might experience reversion is that once the CLP advantage disappears, other municipalities may be more desirable to conduct business in, causing jobs and people to move elsewhere. When looking at the development in Åseral compared to the synthetic counterfactual (the figure on the left) it seems like there is reversion after 1955.

Figure 9: Reversion



Note: The figure shows the synthetic control analysis for Åseral municipality with log population density as the outcome variable. The graph on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graph on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

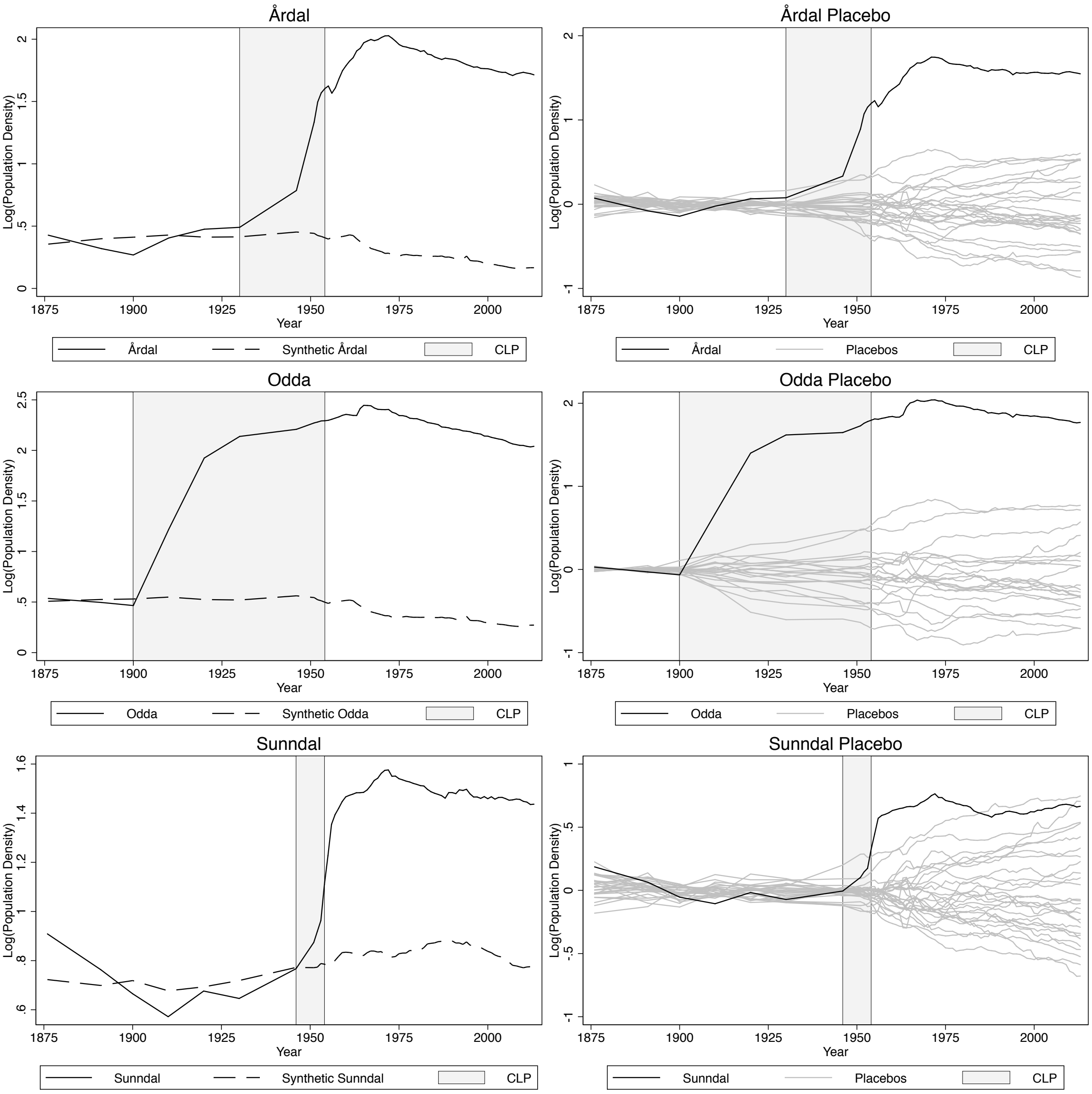
Agglomeration Effects

Figure 10 shows the three municipalities where the analysis gives an indication of agglomeration effects. The figures indicate that all three municipalities had significant CLP effects prior to 1955, and that the growth continued for a period of almost 20 years after 1955. In Årdal's case, the population grew from 2182 in 1946 to 5048 in 1955 (which is an increase more than 130 percent in less than 10 years). The growth further continued after 1955 and the population peaked at 7556 in 1972. However, during the 1970s, the growth rate in all three municipalities declines, meaning that at best there are indications of short run agglomeration effects.

The conclusion in this part of the analysis is that the opening of hydroelectricity plants had significant short run effects due to the CLP advantage in several municipalities, but that no municipalities show signs of significant long run agglomeration effects.

However, we believe that it is possible that even if there are no observable long run agglomeration effects following the CLP advantage with respect to population density, there may be spillovers in other measures of economic activity (productivity for instance) that are not captured by analyzing population density. Consequently, we expand the analysis conducted in Severnini (2014) by utilizing the fact that our dataset includes data on taxable income. This may allow us to uncover agglomeration effects that are not observable when looking at population density, in addition to giving us an indication of the welfare effects of the hydroelectricity plants.

Figure 10: Agglomeration



Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

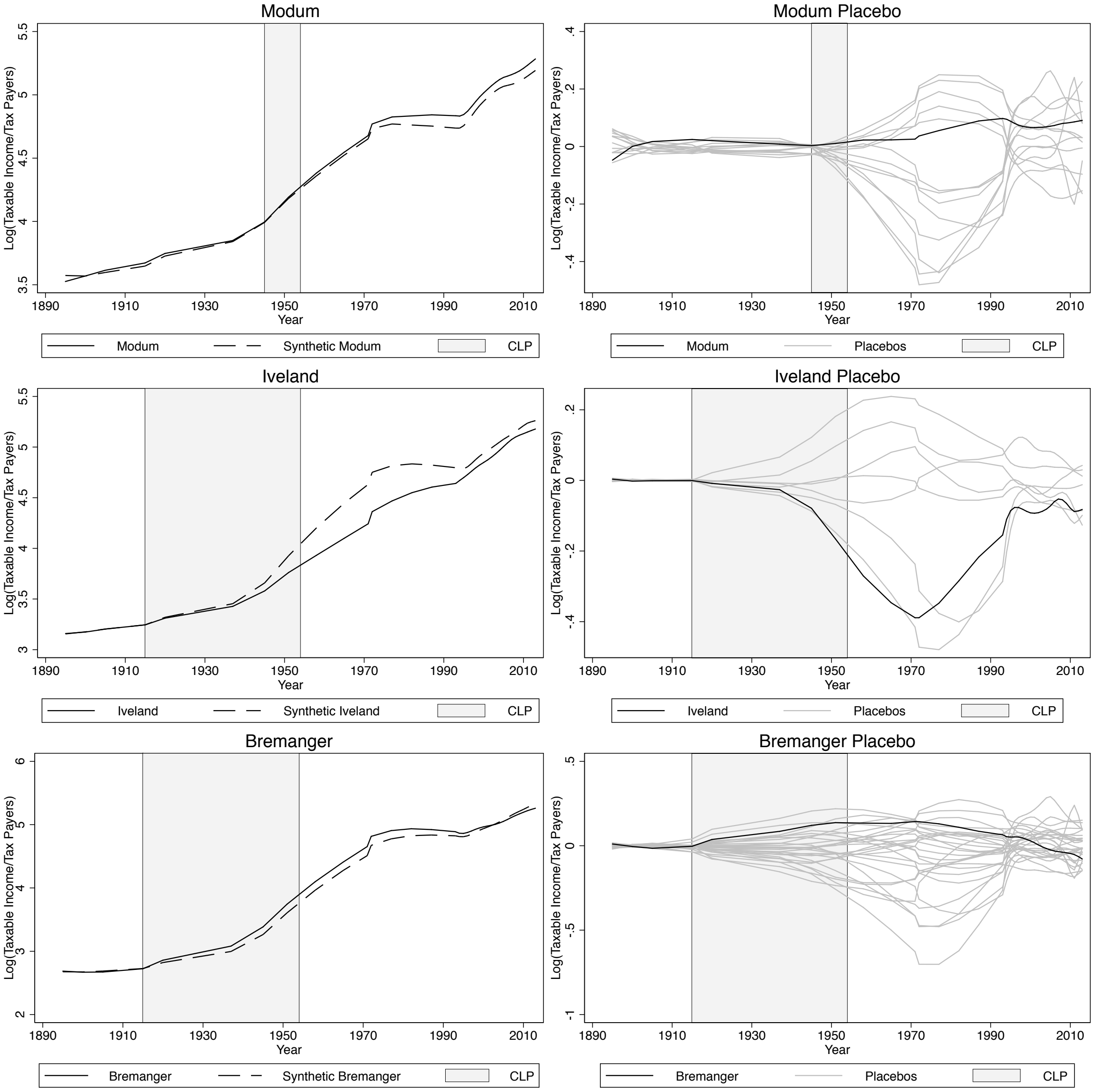
8.1.2 Income

This part of the analysis follows the same procedure and structure as the previous one, apart from the fact that it focuses on taxable income per tax payer as opposed to population density. We have selected some figures to be included in the main text, while the rest can be found in the appendix (Figure A7-A12). The income data have been real price adjusted to real 1998 Norwegian kroner. Additionally, we have applied the HP filter to the time series to make them less volatile. When applying the HP filter, it is necessary to set a value for the parameter λ to determine the level of smoothing to be applied (see equation 5.6). In the macroeconomic literature it is common to set λ equal to 6.25 for yearly data (Ravn and Uhlig 2002), so we choose to use this value as well. Because the observations of taxable income are less frequent than yearly, we have also conducted the analysis using even lower values of lambda (as low as 1) and it does not alter our conclusions.

No Cheap Local Power Effects

Figure 11 shows a sample of three of the municipalities where there are no indications of CLP effects with respect to taxable income. In the top two cases (Modum and Iveland), the figures on the right show that there is no positive development compared to the synthetic counterfactual. In the case of Bremanger there is a positive development, but the placebo study shows that it is not sufficiently strong to be significantly different from the placebos. Such findings are representative for most of the municipalities in the dataset. There are several possible explanations why there are no significant CLP effects when looking at taxable income. One possible explanation is of course that there were no shocks provided by the hydroelectricity plant. This is probably the case in several of the municipalities in this category as they are not the most typical manufacturing municipalities in the dataset. A second possible explanation is that even if there were CLP effects, it is likely that the differences compared to other municipalities they gave rise to were smaller in this part of the analysis. This is because it is less plausible that taxable income would increase as significantly as population density. If the observed differences are smaller, identifying them correctly using the placebo study procedure will also be more difficult.

Figure 11: No CLP

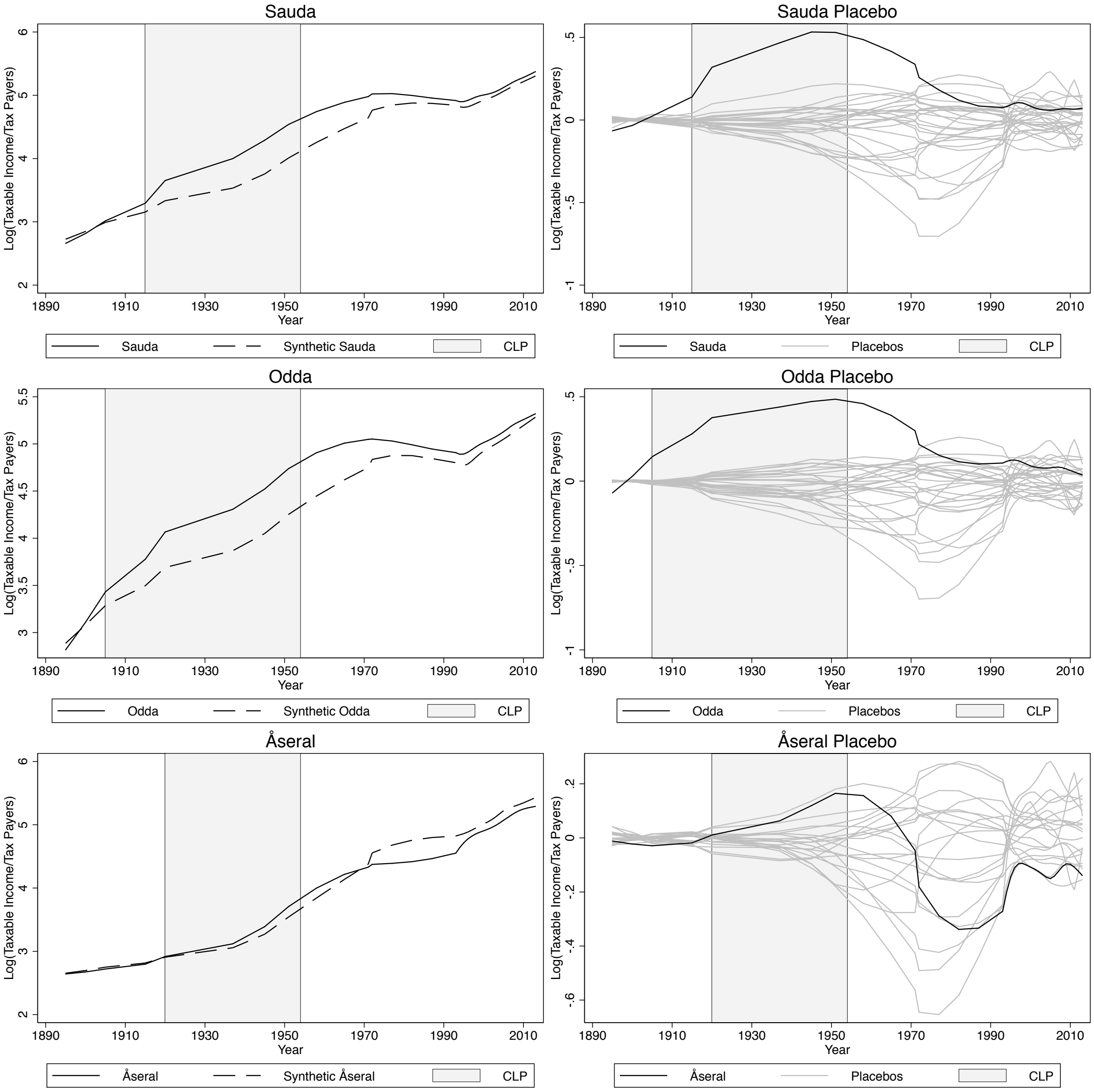


Note: The figure shows the synthetic control analysis for three municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Reversion

Figure 12 shows three of the municipalities where there is a significant CLP effect with respect to taxable income per tax payer, but a reversion of the effect after 1955. Several of the municipalities in this category are among the most typical manufacturing municipalities in the dataset. The interpretation of the findings is that it appears that the opening of the hydroelectricity plant gave a significant increase in taxable income per tax payer in these municipalities, but that after transportation of electricity became possible, their counterfactuals caught up with them. This implies that although there were significant CLP effects, there were no agglomeration effects to make the differences in taxable income per tax payer persist after 1955.

Figure 12: Reversion



Note: The figure shows the synthetic control analysis for three municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

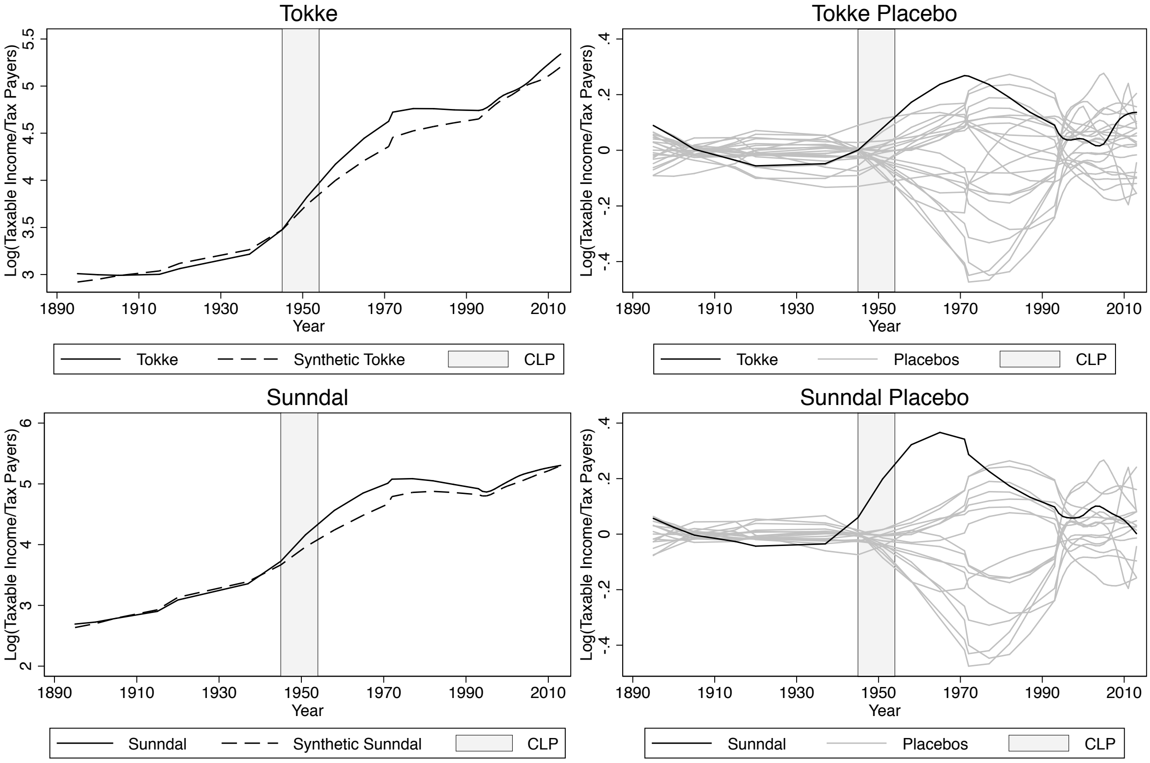
Agglomeration Effects

Figure 13 shows the two municipalities where there is some indication of agglomeration effects. In both cases it is clear that while there is some persistence in the growth rate of taxable income per tax payer relative to the control municipalities, at some point around 1970, the synthetic control municipality starts closing the gap. It is interesting to note that Sunndal exhibits some degree of agglomeration effects both when looking at population density and taxable income. However, we are cautious regarding these results as the hydroelectricity plant in Sunndal was opened rather late, so the development may just be due to increased activity from the development of a large manufacturing plant (which can be interpreted as a delayed CLP effect).

This part of the analysis shows that several of the municipalities had significant growth in taxable income per tax payer following the opening of their hydroelectricity plants. However, it is also clear that in most of the municipalities the growth subsided after 1955. Even in the cases where the growth showed some persistence, it only lasted around 20 years. This means that the arguments for long run agglomeration effects are weak at best.

So far, the analysis has focused on individual municipalities using the synthetic control method. While this is informative, it would also be interesting to obtain some more quantitative measures of the effects in general. Further quantifying the numbers has the advantage that it provides insight into the general effect provided by the hydroelectricity plants. An additional advantage is that because the placebo study procedure is visual and in some cases the conclusion is not clear, obtaining quantitative results may help us arrive at a clearer conclusion. Thus, we now proceed by estimating a model using the rolling out procedure.

Figure 13: Agglomeration



Note: The figure shows the synthetic control analysis for two municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

8.2 Rolling Out

In this section, we estimate average CLP- and agglomeration effects both with respect to log population density and log taxable income per tax payer using the rolling out approach. This approach uses the variation in the data regarding time and duration of treatment to obtain estimates. The model we are going to estimate can be seen in Equation 5.3. We estimate the model using cluster robust standard errors, as well as fixed effects to control for municipality fixed effects. The estimated results are shown in Table 4. Columns 1 and 2 show the estimates with log population density as the dependent variable. Column 1 shows a positive CLP effect, significant at the five percent level, but no statistically significant agglomeration effect. In column 2 the magnitude of the CLP coefficient reduced by about 50 percent (but still significant at the five percent level), while the agglomeration coefficient is still not significantly different from zero. Columns 3 and 4 show the estimates when log taxable income per tax payer is the dependent variable. In this case, the magnitude changes for the CLP effect, and the agglomeration effect stops being statistically significant when using the fixed effects estimator.

As mentioned in the methodology part, the fixed effects estimator is used to control for time invariant municipality specific effects. Failing to do this may bias the results of the analysis if the municipality fixed effects are correlated with the variables in the model. When looking at log taxable income per tax payer, using the fixed effects estimator qualitatively changes the results in the rolling out approach. Given that we have a panel data structure in the analysis and that failing to control for this may potentially bias the results, we argue that the fixed effects models are the ones that provide valid results. This conclusion is strengthened by the fact that the results provided by the fixed effects estimation are most reasonable when looking at the data.

Looking at population density, the results indicate that on average, each year of CLP advantage lead to an increase in population density of approximately 0.691 percent, ceteris paribus, but that there were no agglomeration effects. With respect to taxable income per tax payer, the results indicate that each year of CLP advantage gave an increase of approximately 0.877 percent in taxable income per tax payer. Furthermore, the results indicate that there was no statistically significant difference in the development of the treated municipalities compared to the control municipalities after 1955. A further implication of this is that on average, there was an increase in taxable income per tax payer following the opening of early hydroelectricity plants, but that over time this advantage disappeared. This implies that there are no indications of agglomeration effects when analyzing taxable income.

Table 4: Rolling Out Estimates

	Log Population Density		Log Taxable Income	
	(1) OLS	(2) Fixed Effects	(3) OLS	(4) Fixed Effects
Yearly CLP Effect	1.468** (0.660)	0.691** (0.317)	1.408*** (0.350)	0.877*** (0.257)
Yearly Agglomeration Effect	0.477 (0.668)	-0.0333 (0.184)	0.111*** (0.0410)	-0.205* (0.120)
Constant	122.3*** (11.47)	123.4*** (5.715)	296.9*** (3.858)	296.7*** (3.616)
Yearly Dummies	Yes	Yes	Yes	Yes
Observations	4716	4716	2400	2400
R^2	0.074	0.159	0.939	0.959

Cluster robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

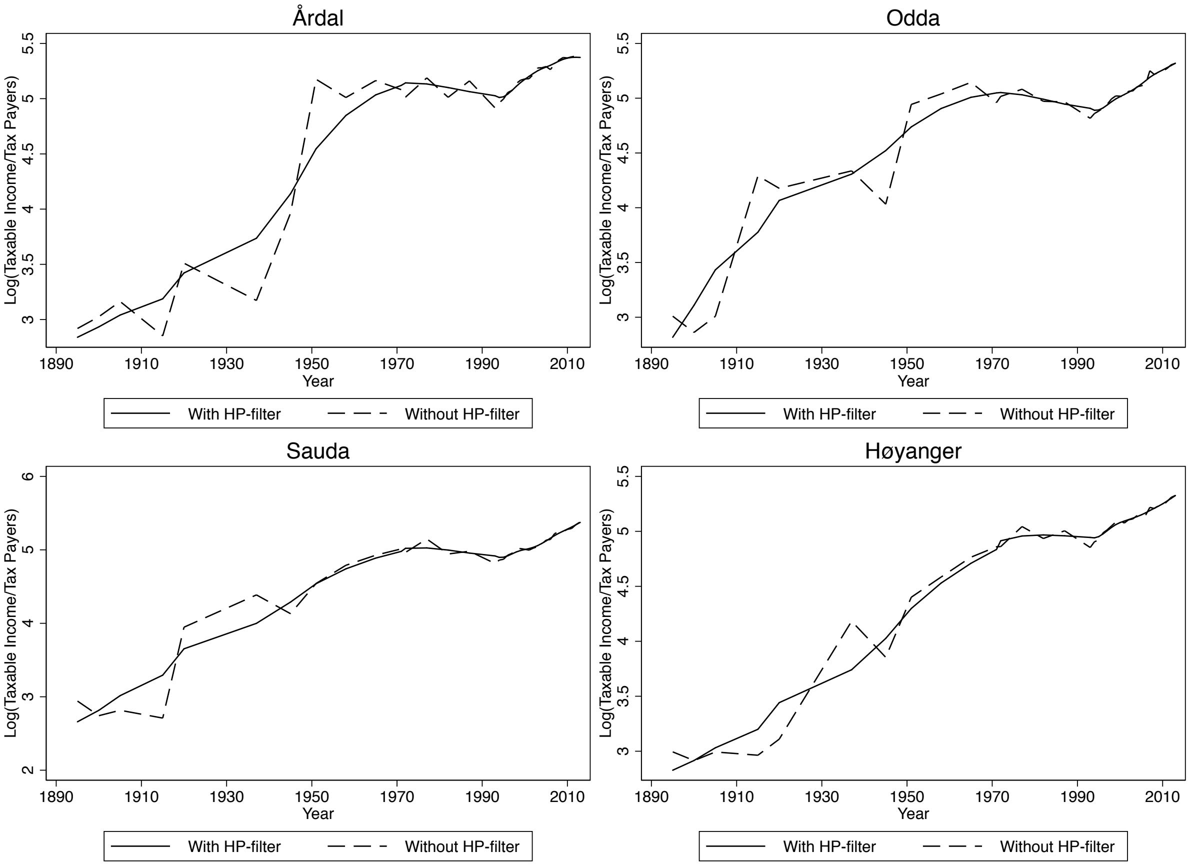
Note: The table shows the estimated cheap local power and agglomeration effects from the rolling out model. Log population density is the dependent variable in the first two columns while log taxable income per tax payer is the dependent variable in the last two columns. Yearly CLP effect is a yearly trend after the opening of hydroelectricity plants. Yearly agglomeration effect is a yearly trend after it becomes possible to transport electricity across large distances (in 1955). The coefficients have been multiplied by 100 for presentational purposes.

9 Discussion

The analysis has some potential issues that need to be discussed. The first one is related to the synthetic control method. When constructing the synthetic control municipalities, we have specified that the size of the turbine initially installed, region and precipitation are used as predictors of our outcome variables. When looking at the synthetic control municipalities, it is apparent that the procedure does in some cases produce synthetic controls that differ with respect to these predictors. This is unfortunate if it implies that the actual and synthetic municipality differ much with respect to factors affecting the outcome variables. However, given that the potential donor pool of control municipalities has its limits, deviations with respect to the predictors is unavoidable in some cases to be able to produce synthetic controls that match pre-treatment development. In order to minimize the impact of this issue we have looked at the constructed synthetic control municipalities and eliminated them in cases where it seems like the procedure produces poor control municipalities. Furthermore, when looking at the results of our analysis, the evidence against long run agglomeration effects is quite compelling, so we do not believe that such differences have affected our results significantly.

There are also some points to be aware of with respect to the data on taxable income. First, both the tax system and the way the tax data is reported has gone through changes in the period we are analyzing. For example, there have been some tax reforms, most notably in 1992 (see Christiansen 2004). Additionally, there have been changes in the way Statistics Norway reported the tax data throughout the period. Given these changes there is some potential for errors in the data, but looking at the time series, they seem reasonable. A second issue is that we have applied the HP filter on the taxable income time series to make them less volatile. This was done in order to avoid having our results affected by short run fluctuations in income that have nothing to do with the long run development. However, using the HP filter may also have reduced the estimated impacts of the hydroelectricity plants, causing our estimated effects to be lower than they should be. Despite this, we argue that it is better to obtain more consistent estimates of the long run development and risk underestimating the effects, compared to finding effects that are caused by random fluctuations. Figure 14 shows a comparison of time series of the actual observations of log taxable income per tax payer and time series that have been smoothed using the HP filter. When looking at the figures, the smoothed series seem reasonable, which strengthens the argument for using the HP filter.

Figure 14: Income HP Filter



Note: The figure shows a comparison between log taxable income per tax payer with and without HP filtering for four municipalities. The smoothing parameter is set to 6.25 when applying the HP filter.

Another potential issue to be aware of is that when constructing our dataset, we had to make some decisions regarding what to do with municipalities that have been merged or divided. The most common case is that smaller municipalities were merged to form a larger municipality at some point. In some of these cases we have chosen to combine the municipalities and analyze them as one unit in the entire time period. Doing this may also have reduced the size of the estimated CLP- and agglomeration effects.

It is also necessary to consider the date we have set for the CLP advantage to disappear. As can be seen in Table 2, there is significant variation in the degree the counties were electrified in different years. This means that it is not possible to find a definitive date that applies to all counties. We have however conducted the analysis using dates as early as 1950 without it altering our main conclusions. This implies that our findings are robust to different end dates for the CLP advantage.

Both the synthetic control method and the rolling out approach in the analysis indicate that opening hydroelectricity plants in Norway in the early 20^{th} century did lead to short run CLP effects in several municipalities, but not long run agglomeration effects. This is in contrast to the conclusion reached by Severnini (2014), who states that he finds significant effects both in the short- and long run. One possible explanation for this is that the hydroelectricity plants analyzed in Severnini (2014) are larger on average than the plants in our dataset. This makes it likely that the shocks they provided to the surrounding area were also larger, which could arguably lead to a higher likelihood of agglomeration effects. Thus, a possible interpretation of our findings is that while shocks to population density and economic activity may lead to agglomeration effects, the likelihood of that happening depends on the size of the shocks.

Because our analysis contains data on taxable income as well as population density, it is possible to draw some additional conclusions compared to Severnini (2014). As the analysis indicates significant CLP effects with respect to taxable income per tax payer, it is arguable that the hydroelectricity plants not only lead to increased population density and economic activity, but also increased welfare. Positive welfare effects from hydroelectricity plants in Norway have also been discovered by Hægeland, Raaum, and Salvanes (2012).

It is clear that there are elements in the analysis that may have confounded the estimates of both CLP- and agglomeration effects. However, we do not believe that these elements have significantly altered the results we have found because even in the municipalities where the effects appear strongest, the evidence in favor of long agglomeration effects is weak.

10 Conclusion

The aim of the analysis has been to answer the research question *"To what extent did the shocks to economic activity and population following openings of Norwegian hydroelectricity plants in the early 20^{th} century lead to long run agglomeration effects?"*. To answer the question we have used a combination of the synthetic control method and the rolling out approach to analyze both the development in population density and taxable income in a sample of Norwegian municipalities.

The synthetic control method showed that opening hydroelectricity plants led to significant increases in both population density and taxable income in a range of municipalities. When looking at population density, the analysis further revealed that when the CLP advantage disappeared around 1955, so did the growth in population density in most municipalities, indicating that there were no long run agglomeration effects. However, in three municipalities there was an indication of agglomeration effects, but in all of these municipalities the growth eventually subsided.

With respect to taxable income, most of the municipalities with positive CLP effects had negative developments relative to their synthetic controls after 1955, which can be interpreted as reversion. It is important to keep in mind that this does not entail that the taxable income in these municipalities fell after 1955, but that the growth was lower than in the synthetic controls. In two of the municipalities there were indications of agglomeration effects similar to those found when looking at population density. However, given that even in the cases where there were some indications of agglomeration effects, the effect disappears after around 20 years, the most reasonable conclusions is that there is little evidence in favor of agglomeration effects when looking at taxable income.

Summing up, the synthetic control method revealed significant CLP effects, but no significant indications of long run agglomeration effects for either of the outcome variables. A challenge in this part of the analysis is that the synthetic control method relies on the placebo study procedure, which relies on visual interpretation and does not produce quantitative estimates. This means that in some cases, it is not entirely clear how the results should be interpreted. As a consequence of this, we also conducted an analysis using the rolling out approach, allowing us to obtain even clearer and quantifiable results.

Also in the rolling out part of the analysis the estimates indicated significant positive CLP effects on average regarding both population density and taxable income. The analysis further revealed that the development with respect to both outcome variables was negative relative to the control municipalities after 1955, but this effect was not significantly different from zero at the five percent level. This further strengthens the conclusion that the hydroelectricity plants lead to significant short run effects on average, but these effects disappeared after 1955, indicating that there were no long run agglomeration effects.

10.1 Implications

The research question addressed is interesting both from a theoretical perspective as well as from a policy perspective. Our findings have implications for both. From a theoretical perspective the findings imply that there are limits to how strong agglomeration effects are in some contexts. Even though the hydroelectricity plants provided significant shocks to the treated municipalities, these effects were not strong enough to persist after the initial shock subsided. This is not to be interpreted as evidence that agglomeration effects do not exist, but it means that stating that increasing the number of people in an area increases productivity may not be correct in all cases. We believe this is a useful contribution to the theoretical debate surrounding the economics of urbanization.

Furthermore, the findings have implications concerning policy decisions. The findings imply that while it is possible to increase population and economic activity in remote areas by providing shocks, assuming that such policy interventions will result in long run growth as well is not necessarily correct. In the Norwegian context this implies that while allowing for potential harms to the environment from oil drilling and mining may well lead to short run growth, the development in the long run is much less certain. This is important because assumptions regarding the long run development are very crucial when determining the costs and benefits of policy interventions.

11 References

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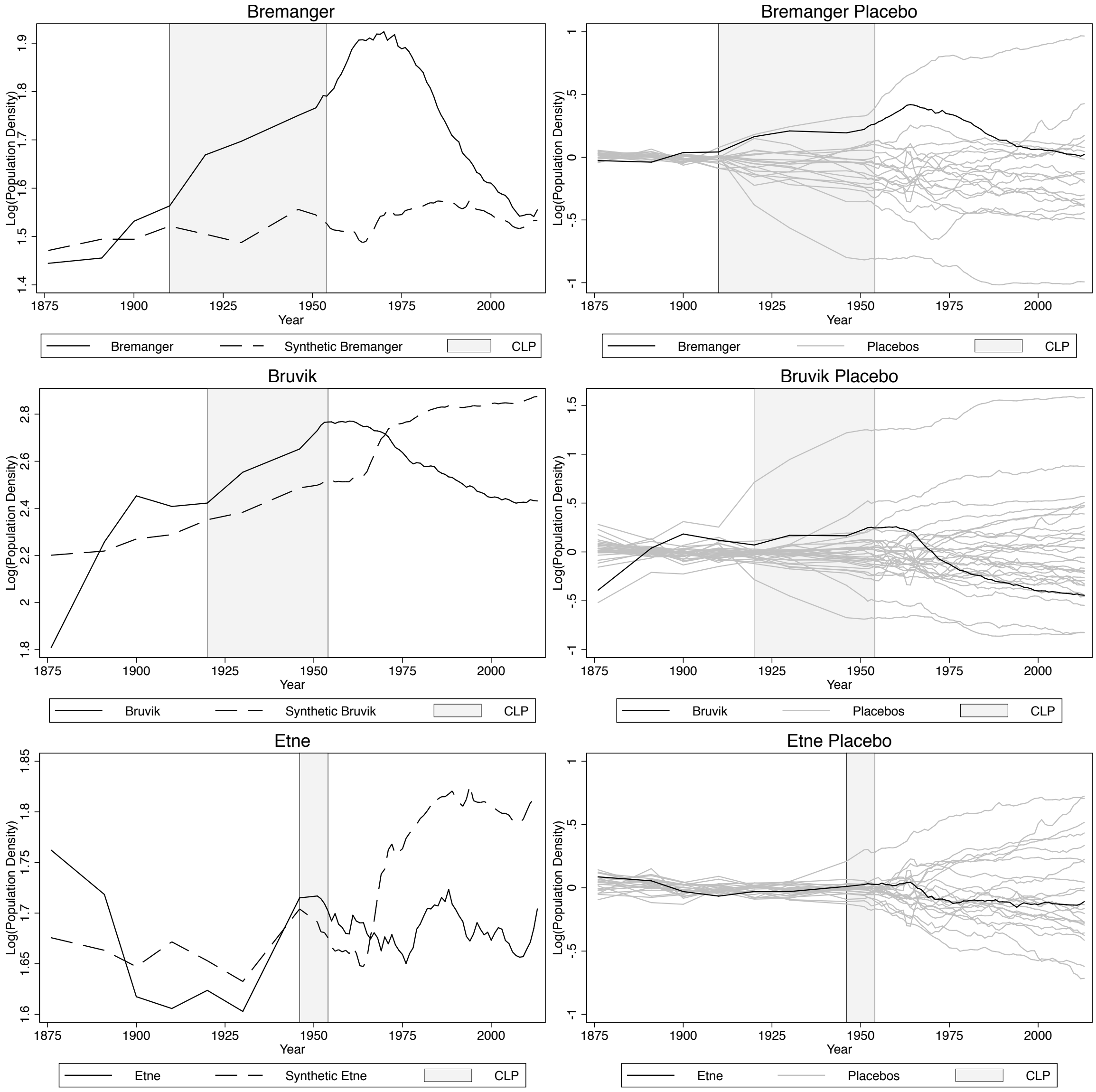
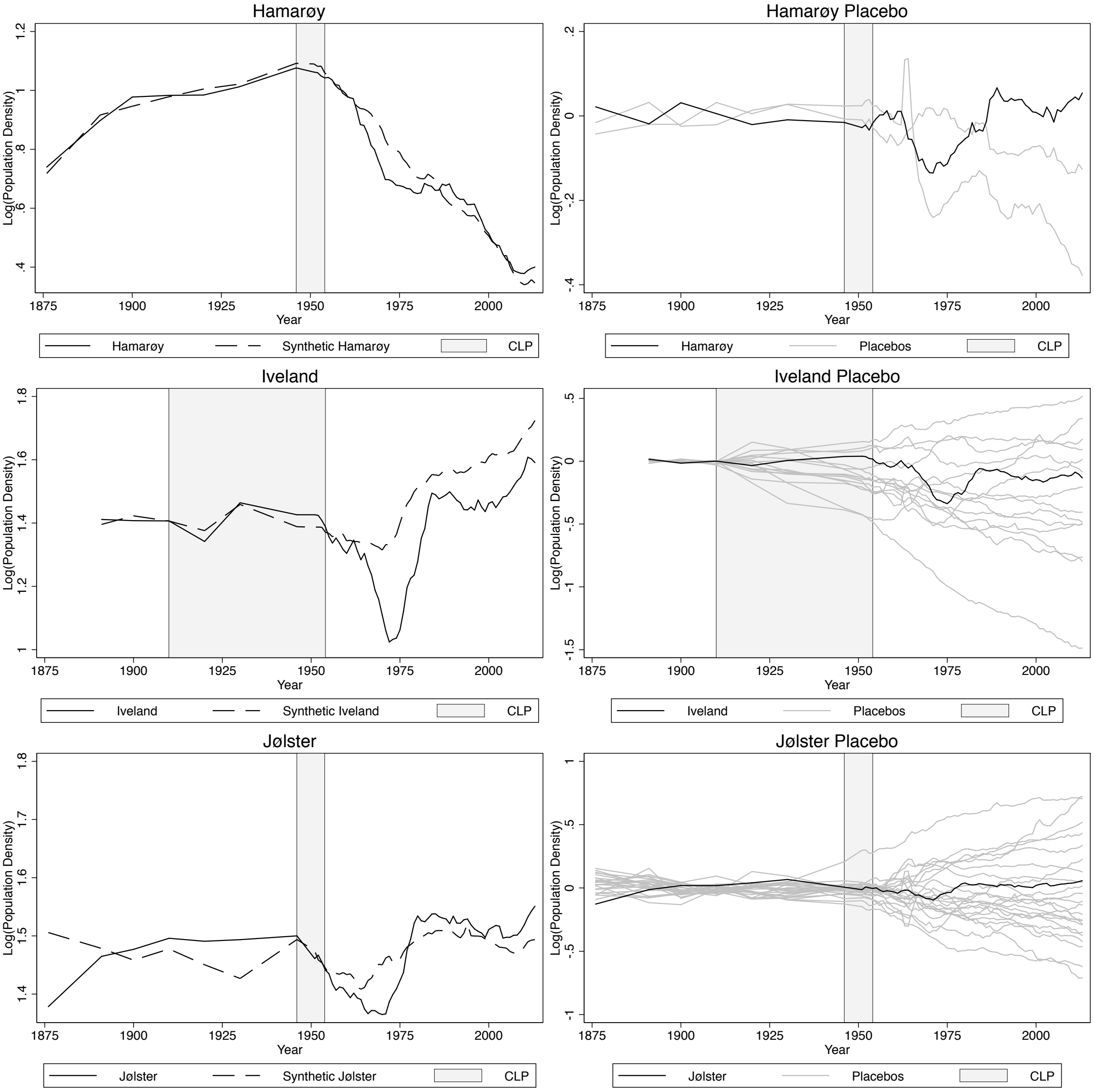
12 Appendix

Figure A1: Population Density 1



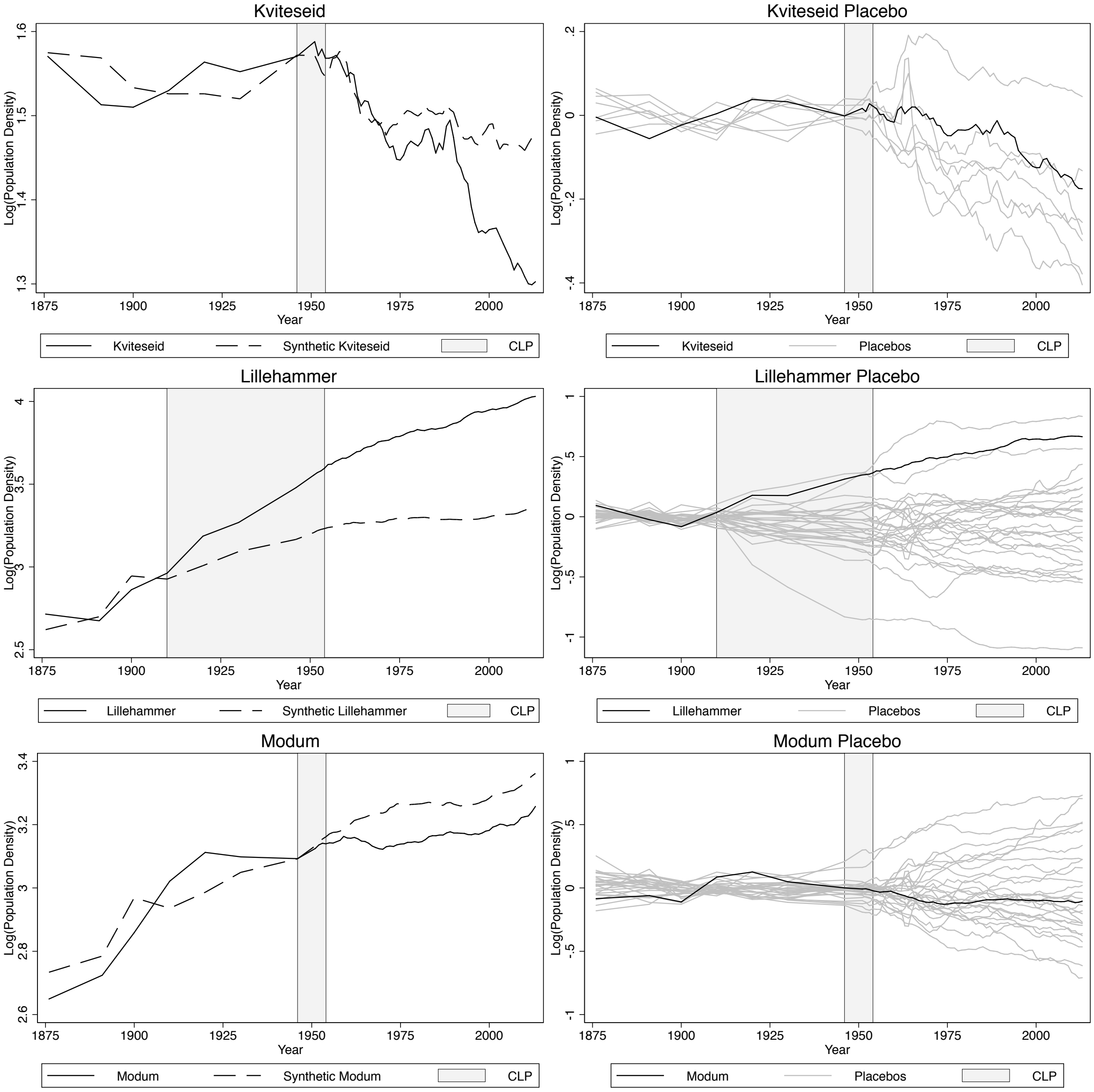
Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A2: Population Density 2



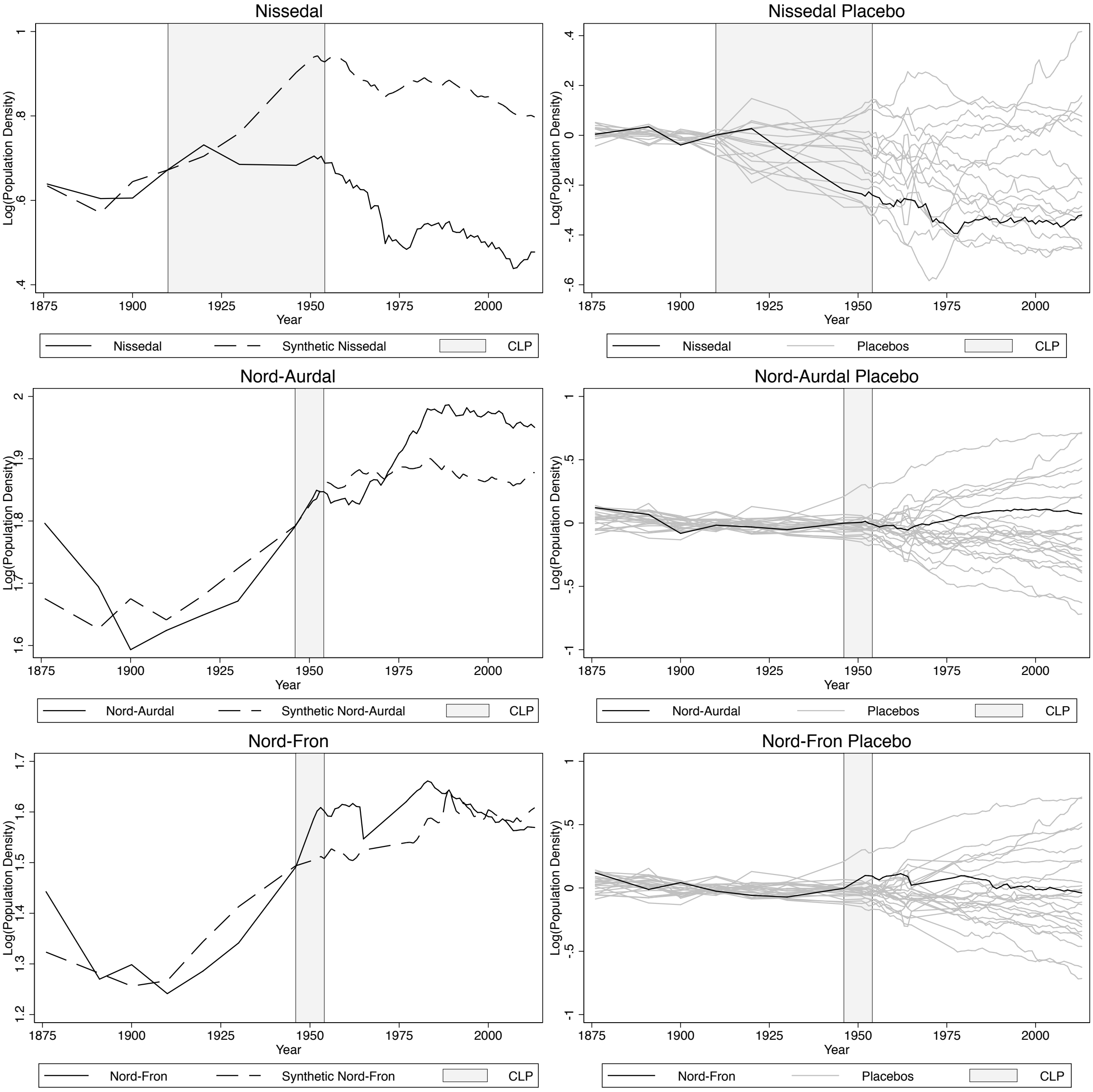
Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A3: Population Density 3



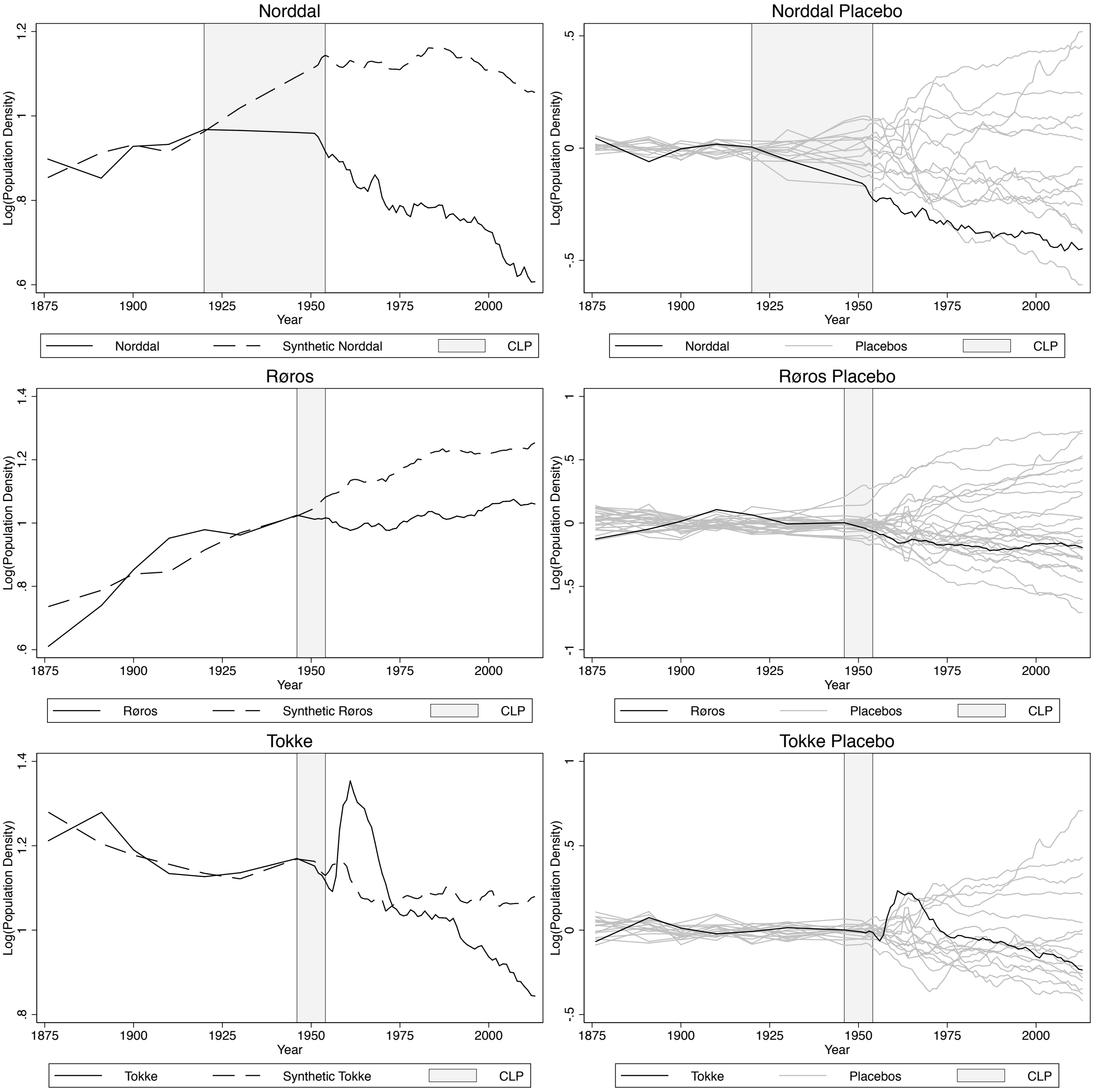
Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A4: Population Density 4



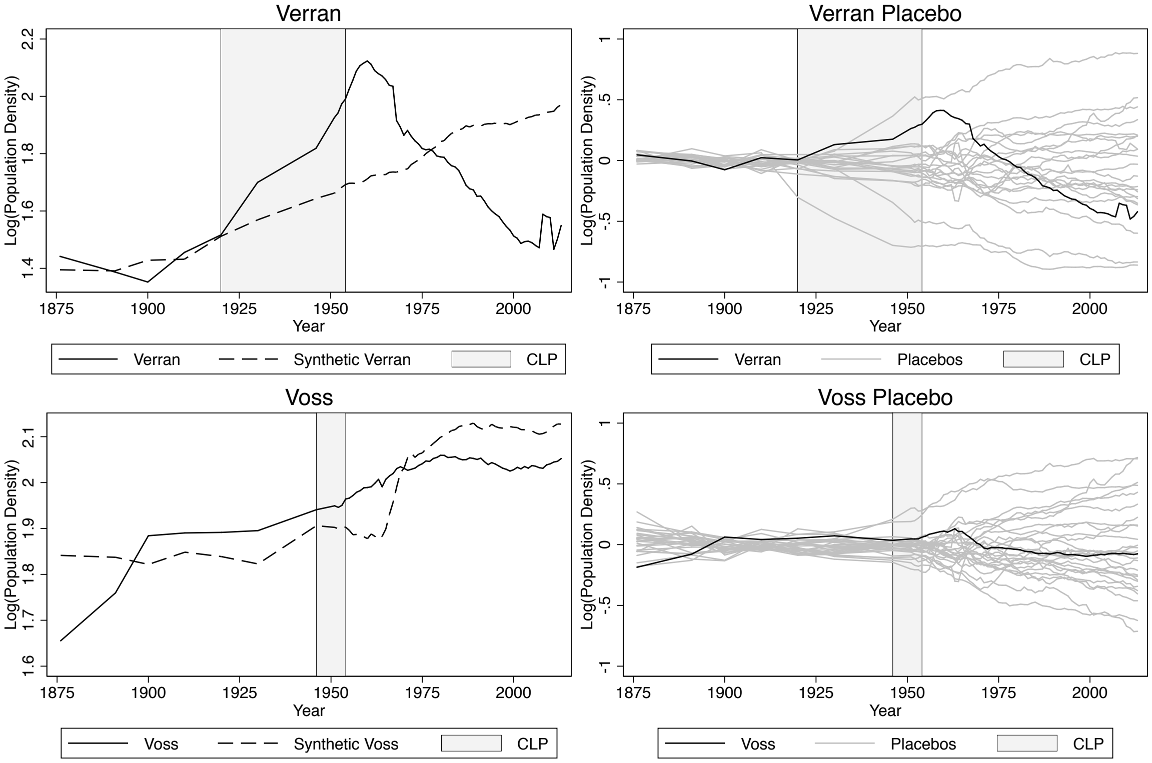
Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A5: Population Density 5



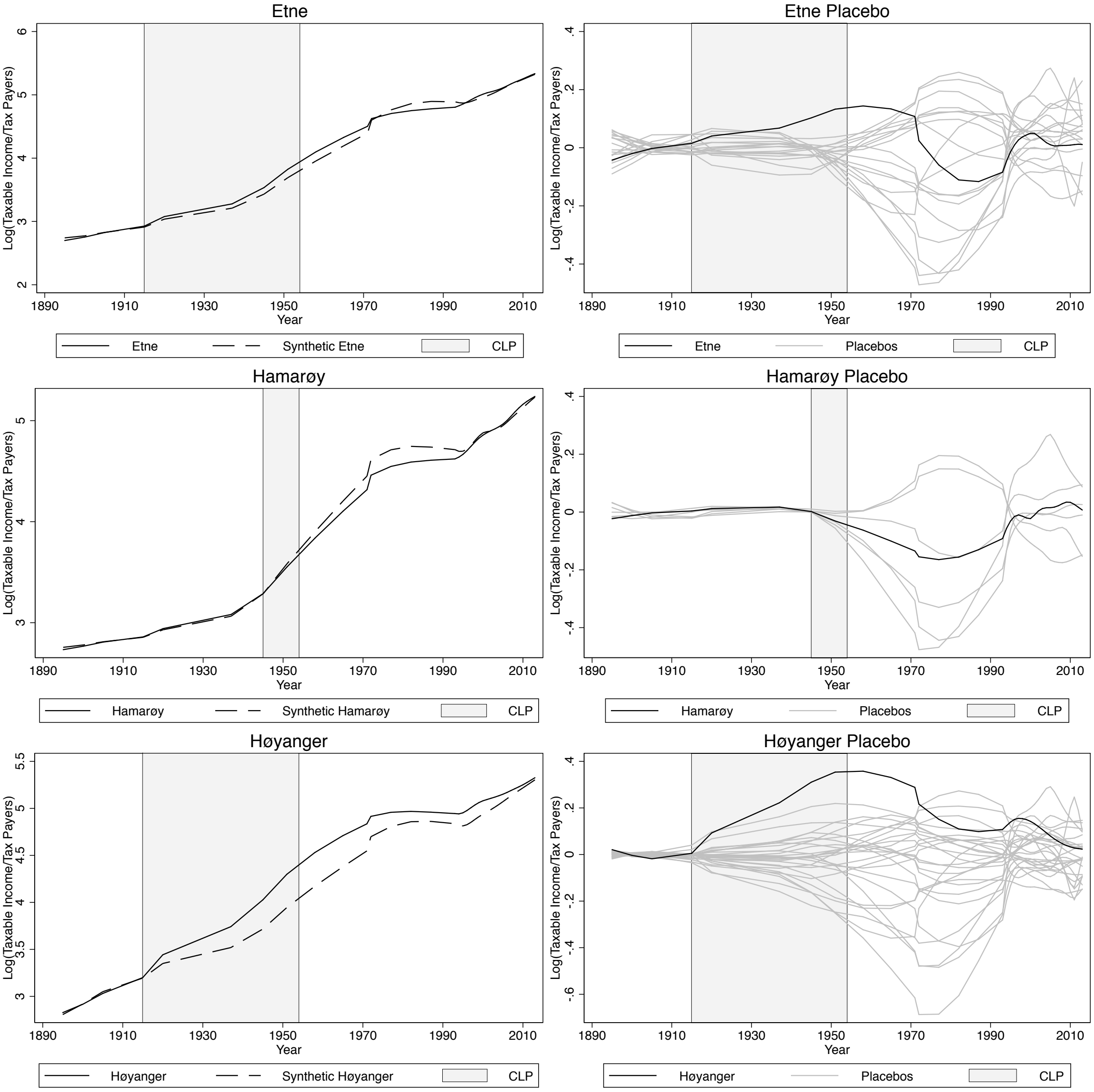
Note: The figure shows the synthetic control analysis for three municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A6: Population Density 6



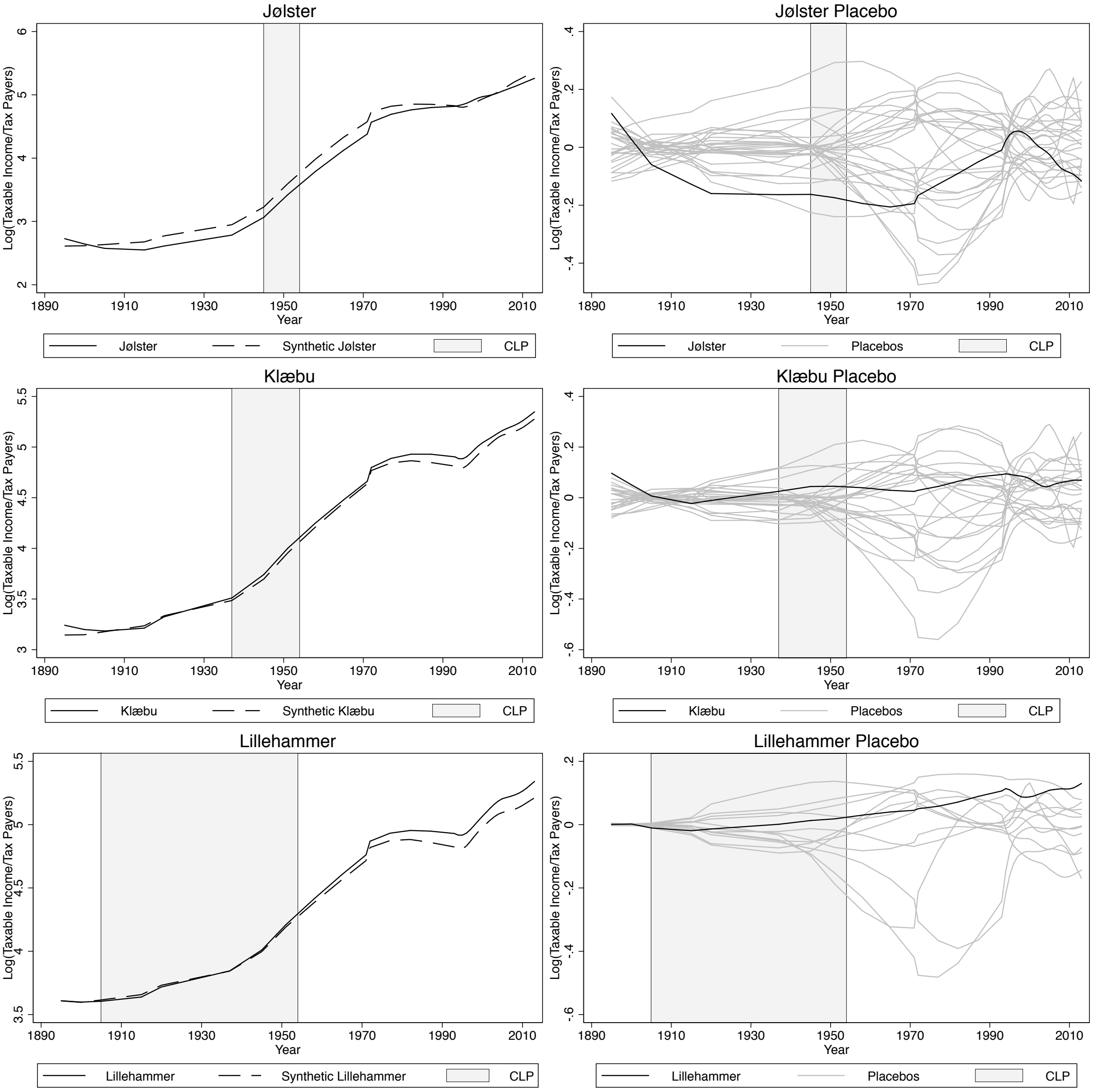
Note: The figure shows the synthetic control analysis for two municipalities with log population density as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A7: Taxable Income Per Tax Payer 1



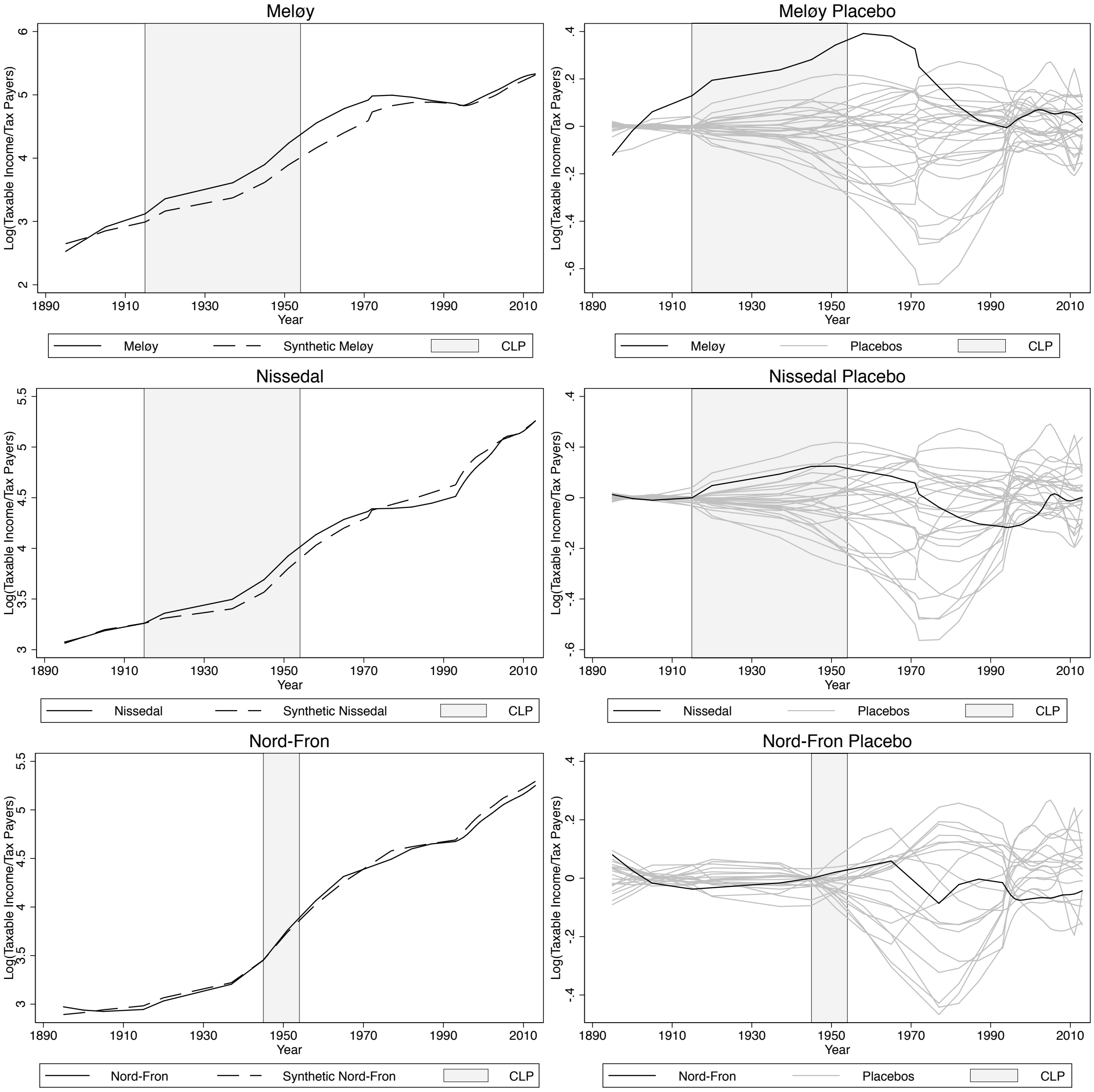
Note: The figure shows the synthetic control analysis for three municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A8: Taxable Income Per Tax Payer 2



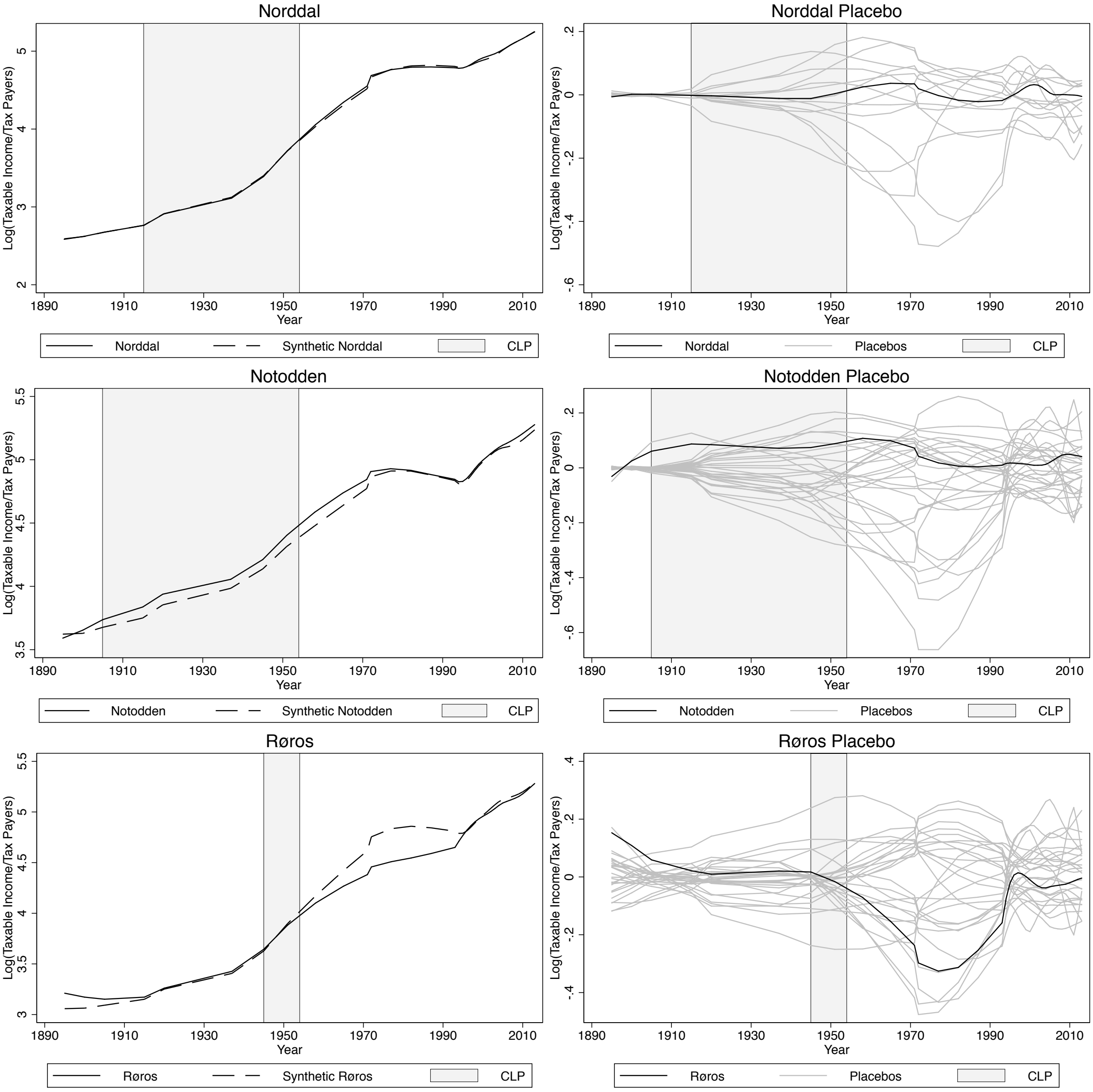
Note: The figure shows the synthetic control analysis for three municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A9: Taxable Income Per Tax Payer 3



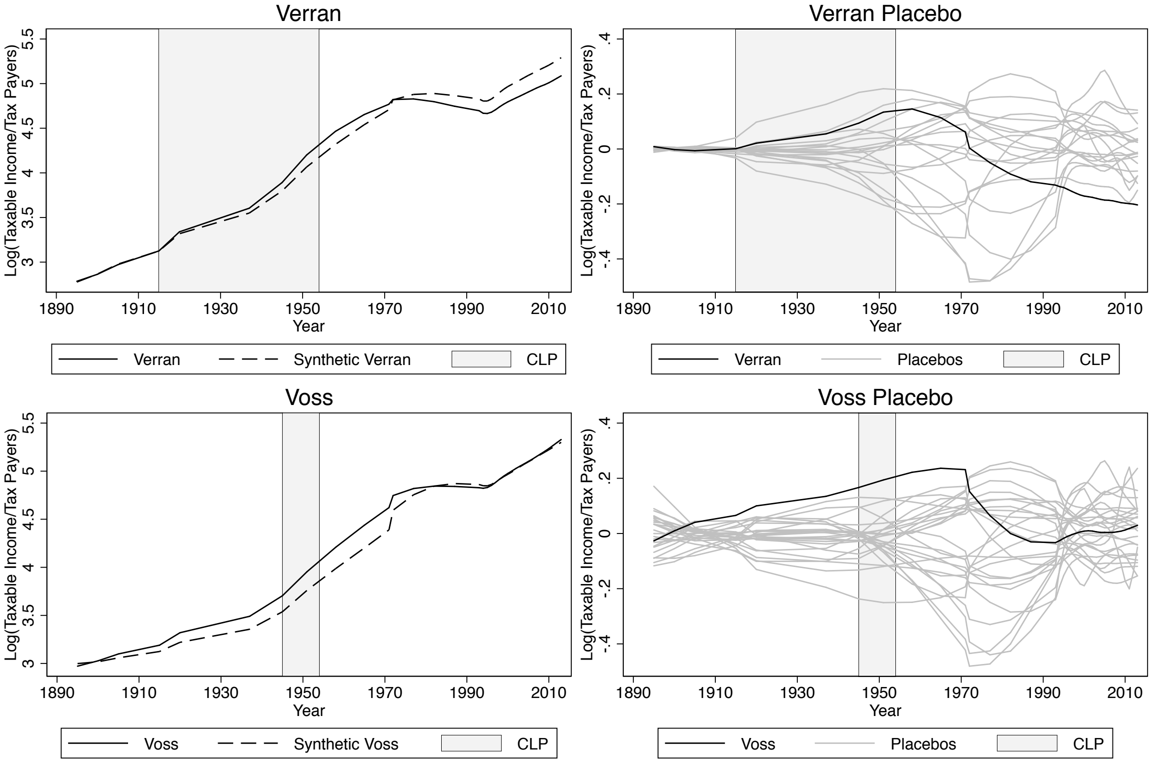
Note: The figure shows the synthetic control analysis for three municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A10: Taxable Income Per Tax Payer 4



Note: The figure shows the synthetic control analysis for three municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A11: Taxable Income Per Tax Payer 5



Note: The figure shows the synthetic control analysis for two municipalities with log taxable income per tax payer as the outcome variable. The graphs on the left show the actual observations of the municipality compared to the values in the synthetic control municipality. The synthetic control municipality is a weighted average of a potential donor pool of municipalities constructed to match the pre-treatment values of a set of economic predictors in the treated municipality. These predictors are average log population density, log population density in the latest pre-treatment observation, production capacity of the turbine initially installed in the hydroelectricity plant, what region the municipality is located in and average yearly precipitation in the county the municipality is located in. The graphs on the right show placebo studies as proposed by Abadie, Diamond, and Hainmueller (2010). The grey area shows the years between the hydroelectricity plant was opened and when transportation of electricity across long distances is assumed to be possible (1955), i.e. the period when the municipality had a potential cheap local power advantage.

Figure A12: Taxable Income Per Tax Payer 6

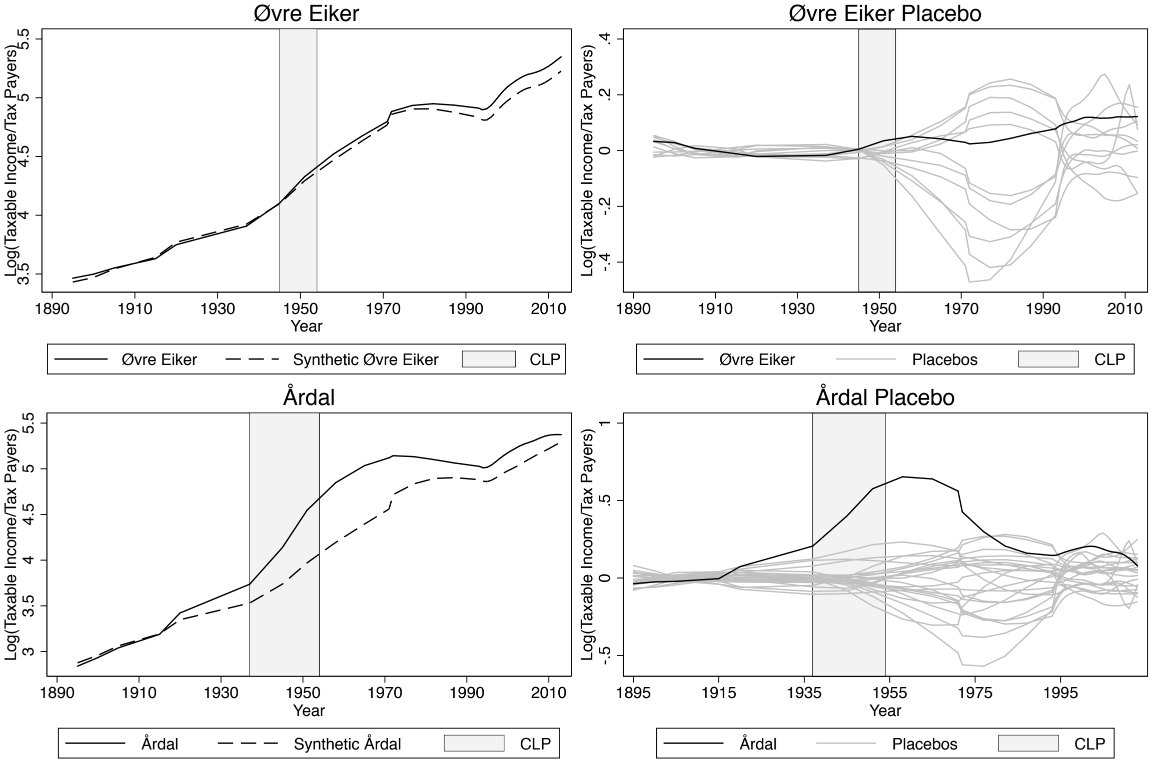


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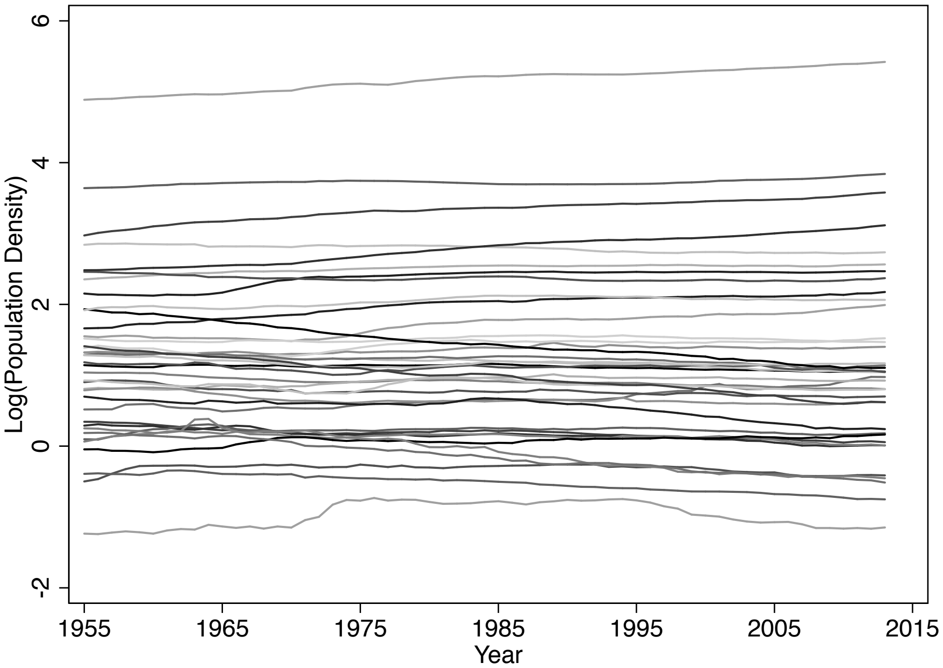
Figure A13: Population Density in the Control Municipalitites



Note: The figure shows the development in log population density in all the possible control municipalities in the dataset in the period between 1955 and 2013. Each line represents one municipality.