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Abstract:

This paper studies the impact of the construction of hydropower facilities on labor market outcomes in Norway at the turn of the twentieth century (1891-1920). The sudden breakthrough in hydropower technology provides a quasi-experimental setting, as not all municipalities had suitable natural endowments and the possible production sites where often located in remote areas. We find that hydropower municipalities experienced faster structural transformation and displayed higher occupational mobility. Unskilled workers and workers from low-status families did to a greater extent obtain skilled jobs in hydropower municipalities. We interpret this as evidence that this early twentieth-century technology was skill-biased, and that workers in the new skilled jobs were recruited from a broad segment of the population. However, areas affected by the new technology also experienced occupational polarization, with an increase in high- and low-skilled manual jobs at the expense of intermediate-skilled jobs.

Keywords: industrial revolution, hydropower production, structural transformation, occupational mobility, intergenerational mobility

JEL classification: J62, N7, N9, R1, R12

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Sammendrag

Teknologisk endring har dyptgripende påvirkninger på arbeidsmarkeder. Dette gjelder både historisk og i nåtid, og slik vil det sannsynligvis også være i framtiden. I tillegg til å øke produktiviteten og veksten i økonomien, har teknologiske framskritt også endret arbeidernes muligheter. På kort sikt vil det være justeringskostnader og tap av jobber, men framskritt skaper også nye jobber og muligheter for arbeidere å klatre på yrkesstigen. Yrkesmobiliteten ved slike omskiftninger kan, som vi skal vise, avhenge av arbeideres yrkeserfaring og bakgrunn.

I et historisk perspektiv har forskere ofte fokusert på den industrielle revolusjonen for å undersøke konsekvensene av teknologiske framskritt. Bevisene fra seint på 1800-tallet og tidlig på 1900-tallet spriker noe. Ofte er det begrensede økninger i levestandard i den tidlige bølgen av industrialisering, mens senere bølger viser positive utfall drevet av økt etterspørsel etter arbeidskraft til yrker med høyere krav til arbeidernes ferdigheter. Det er generelt vanskelig å identifisere og kvantifisere effekten av teknologisk endring på arbeideres utfall siden teknologiendringer skjer gradvis.

I dette forskningsarbeidet utnytter vi bruken av vannkraftteknologi som et kvasi-eksperiment for teknologisk endring. I tillegg til data om vannkraftutbygging anvender vi norske folketellingsdata fra 1891-1920 med detaljert informasjon om bakgrunn, yrke og demografi. Denne historiske hendelsen er egnet for formålet siden 1) vannkraftteknologien brøt igjennom plutselig og ble raskt tatt i bruk i Norge, 2) vannkraft kunne bare genereres på steder med passende geografi og 3) energien kunne bare i begrenset grad transporteres. Vi undersøker hvordan dette skiftet påvirket lokal befolkningsstørrelse, næringssammensetning og arbeideres yrkesmobilitet over tid og mellom generasjoner.

Vi finner bevis for strukturell endring av den lokale økonomien ved teknologiendring. I vannkraftkommuner øker befolkningen mer og produksjon i primærsektoren substitueres i større grad med industri- og tjenesteproduksjon. Arbeidere i manuelle lav-ferdighetsyrker og deres sønner har større sannsynlighet for å avansere til høyere stillingskategorier. Det ser dermed ut til å være et positivt skift i etterspørsel etter arbeidere til høy-ferdighetsyrker i kommunene som tar i bruk vannkraftteknologi. Ved å rangere lav-ferdighetsyrker etter status og lønn, ser vi at mobiliteten til arbeidere i lav-ferdighetsyrker i vannkraftkommuner har en polariserende effekt på fordelingen. Det er de i midten av fordelingen i disse yrkene som avanserer, og arbeidere i yrker med lavest status får ikke i like stor grad nyte godt av teknologiendringen.

1 Introduction

In large parts of the world, the impact of the Industrial Revolution was beginning to be felt in earnest around the turn of the twentieth century. The adoption of existing technologies as well as new technological breakthroughs profoundly altered the economic and social composition of local communities. On one hand, these advancements led to positive outcomes like productivity growth and higher incomes. On the other hand, benefits were not equally distributed, and there were short-term adjustment costs as well as a permanent loss of certain types of jobs. Fear of technological change has lingered throughout modern history. In the early 19th century, Luddites broke textile machinery in order to attract attention to and hamper technology-induced unemployment and deteriorating labor market opportunities for artisans. For better or for worse, technological progress affected different type of workers in different ways and continues to do so today.

Empirical evidence of the impact of technological change in the late nineteenth and early twentieth centuries has generally been ambiguous. Accounts of the early stages of the industrial revolution emphasize that improvements in standards of living were limited (Clark, 2005), while later waves are more often associated with positive outcomes brought about by skill demand (Goldin and Katz, 1998). However, due to the gradual development of technologies, it is often not possible to identify the relationship between technological improvements, structural transformation and labor market outcomes for workers of different skills and backgrounds.

In this paper we provide evidence of the heterogeneous impact of rapid technological development by exploiting the expansion of hydropower technology in Norway from 1890 onward as a quasi-natural experiment. The key features of the research design are the highly localized nature of hydropower production and the abruptness of adoption. Hydropower plants depend on geographical properties — the terrain must be suitable (with a sufficient slope), and there must be enough water flow. Early on, when transmission technology was still in its infancy, electrical power had to be produced close to where it was to be used (Hughes, 1993). These conditions make it feasible to compare outcomes across municipalities with different natural attributes. In this way we provide evidence of changes in the local economic conditions and in the social mobility of workers caused by technological change. To test the validity of the approach we apply several estimation strategies, including instrumental variable methods, fixed effect models and sample restrictions.

Norway is a suitable context for this study for several reasons. At the time, the Norwegian economy had undergone only a limited industrial revolution (Venneslan, 2009). Over the next thirty years, more than 140 hydroelectric power plants would be constructed, often in relatively remote areas with mostly agrarian production. The technology was imported from abroad, and partly financed with foreign capital. The historical circumstances make it less likely that the results are affected by unobserved characteristics. In addition, access to rich population-wide census data makes it possible for us to explore these questions in depth.

In the related literature on technological development and skill demand, little is known about the layers of society from which new skilled laborers are recruited, and whether occupational mobility was most common among locals or among newcomers. This is something we can investigate with linked census data, where changes in an individual's occupation over time can be examined. In addition, the present study contributes to our knowledge of the consequences of technical change outside of the core industrial economies of the early twentieth century. The Norwegian case is interesting in its own right, as the level of formal education and training in Norway was very low compared to economies like Great Britain or the United States, though literacy levels were high.

To investigate the local effects of hydropower technology adoption, we proceed in two steps. First, using municipal data, we investigate how the labor force size and the sectoral employment shares are affected by hydropower technology. Second, we examine how general and intergenerational occupation mobility vary across hydropower and non-hydropower municipalities. For this purpose, we use linked census micro data, and distinguish between workers belonging to different occupational groups. We show that municipalities that adopt the new technology have a relatively larger increase in the local labor force. We also find evidence of faster structural transformation, as hydropower municipalities display an expansion in employment in manufacturing and services at the expense of the agricultural sector. The construction of power plants and changes in the industrial structure are found to be related to the occupational mobility of workers, especially at the lower end of the skill distribution. Low-skilled manual workers are more likely to obtain higher-skilled positions in hydropower municipalities, and the intergenerational mobility of sons of unskilled workers is relatively higher in these municipalities. Focusing on a finer range of manual occupations reveals some evidence of a hollowing out of the skill distribution, as the upward mobility induced by hydropower technology adoption lifts those in the middle. This claim is supported by analyses of occupational employment shares, where the growth in employment is found to be at the extremes of the distribution.

The paper is structured as follows. Section two provides a brief account of the industrialization process in Norway and a short literature review. The third section explains the empirical strategies and describes the data. Section four provides the results of the aggregate analyses of population size and structural transformation. In Section five we investigate how hydropower production is related to occupational mobility, and in Section six we follow up by exploring whether it contributed to polarization of the occupation structure. Section seven provides a conclusion.

2 Literature

2.1 Industrialization and hydroelectricity in Norway

Norway was a relatively late industrializer compared to the rest of Western Europe. By the end of the nineteenth century, 11.9 per cent of the population was employed in manufacturing, compared to eight per cent in 1875 (Statistics Norway, 1978, p. 36). Manufacturing was mostly an urban phenomenon; this is attributed by Hodne and Grytten (2000, p. 210) to several attractive outside (e.g. non-agricultural) options in the countryside, including fisheries and employment at sea. Waterfalls had been utilized for economic production for a long time; sawmills powered by water ("oppgangssager") were established from the early sixteenth century onward (Helle et al., 2006, p. 160) and river flour mills were also used early on. The conversion of water potential into electrical energy greatly expanded its possible applications. Yet, the use of hydroelectric power started on a small scale.

The first large-scale use of energy from waterfalls to generate electricity was demonstrated in the 1880s in the United States. The first hydropower installation in Norway (and in Europe) was constructed at Senjens Nickelworks in 1882 and had a production capacity of a meagre 6.5 kW. In Norway, the first electric plant that also functioned as a supply station for subscribers was established at Laugstol Works, a woodworking company, in 1885 (Bjorsvik et al., 2013). Initially the small power plants were mainly used for lighting in manufacturing plants, privately owned houses and streets.

It was the establishment of the electro-chemical industry that pushed the Norwegian economy into widespread industrialization. At the turn of the century the production of carbide was initialized: first at Sarpsborg in 1899 (Hafslund and Borregaard), next at Meråker in 1900 (Meraker Bruk) and finally at Notodden in 1901 (Notodden Calcium Carbidfabrikk). At the time there was a widespread fear of a world shortage of nitrogen, which was crucial to the production of fertilizer and explosives (Hodne, 1975). Norsk Hydro built Svælgfos power plant in 1905, the largest of its kind in Europe, to produce potassium nitrate using a new technique developed by Birkeland and Eyde (Jensen and Johansen, 1994). The economic significance of this invention cannot be understated: suddenly agricultural production was again assured. Exports of Norway saltpetre amounted to 70 900 tons in 1913 and increased to 117 000 tons by 1920 (Hodne, 1975).

Science advanced, and new patents on the use of electrolysis for metal smelting became known. Norway had a comparative advantage in applying these methods because of its favorable hydropower production conditions, which led to the establishment of an electro-metallurgical industry. The industry produced iron, zinc, nickel and aluminum at competitive prices. The first aluminum production in Norway started in 1906, while the first electrical steel smelter was built in 1909 (Jensen and Johansen, 1994).

These hydropower-related industries boomed during World War I, and many new local industry communities were established. The cause of this upswing appears to have been the inflow of capital from abroad and increased demand for electro-chemical and electro-metallurgical products for the war machine. The rationing of coal and petroleum products also led to higher household demand for the relatively cheap electricity for use in cooking, lighting and heating. The expansion of municipality-owned hydropower plants did not accelerate until 1905. The older municipality-owned power plants were mostly located in cities and were small. In 1900, every tenth household had electric lighting, while two thirds were covered in 1920 (Jensen and Johansen, 1994).

A substantial part of the financing of new industries in Norway came from abroad. There was a current account deficit of between 16 and 33 per cent of gross investment in the period 1895-1914, and 39 per cent of listed manufacturing firms were foreign-owned in 1909 (Hodne and Grytten, 2002, p. 44). Laws restricting private and foreign ownership of waterfall rights were enacted in 1917, mandating reversion to government ownership after 60-80 years. As a result, there were fewer private and more public projects after this year (Hodne and Grytten, 2002, p. 28).

2.2 Skill supply and demand

The classical model of economic growth formalized by Lewis (1954) effectively assumed an unlimited supply of labor. If this held true, a modern industrial sector could expand without the limiting effect of increasing wages. High emigration rates in Norway in the late nineteenth and early twentieth century do suggest some features of such a "surplus population" economy. However, substantial income differences between rural and urban areas (Statistics Norway, 1915) show that a "strong version" of the Lewis model, in which workers in the industrial sector also only earn a subsistence wage, is unlikely to fully capture the dynamics of the Norwegian industrializing economy. Rather, technology and capital worked together to provide new types of jobs, with different skill profiles.

The canonical reference on technology-skill complementarity is Goldin and Katz (1998), who provide a framework for understanding the relationship between technological development and investment. Using data on United States industries between 1909 and 1940, they find that industries that used more capital employed higher-educated workers and paid higher education premia. This is in contrast to research on earlier periods, in particular nineteenth-century Great Britain, where high-skilled workers and capital appear to have been substitutes. Acemoglu (2002) argues that this difference stems in part from the high supply of unskilled labor in Great Britain in the nineteenth century, which provided an incentive for the development of technologies utilizing low-skilled labor. Later, increases in the supply of skilled workers led to development of skill-complementary technologies.

In recent years, technological change in many countries appears to have become routine-based rather than skill-based. There has been a polarization of the job distribution ("hollowing out"): a decrease in jobs with intermediate returns and an increase in high- and low-return jobs (Autor et al., 2006; Goos et al., 2009, 2014). Similar patterns have also been found in historical data (Gray, 2013; Katz and Margo, 2014).

Disentangling the effects of skill supply and demand is a challenging task. However, in the case discussed in the present paper, the technology was to a large extent imported from abroad (though important adjustments were made domestically), and partly financed with foreign capital. Norwegian workers had a low level of formal training, but a high level of basic human capital (reading and writing skills) often attributed to the Scandinavian elementary school system and the prevalence of state-sponsored Lutheranism (Sandberg, 1979).

The level of economic mobility in Europe during the early Industrial Revolution is generally believed to have been limited. Long and Ferrie (2013) document that while intergenerational mobility in the United States was high in the nineteenth century, it was much lower in Great Britain. Mobility in Norway was also low (but increasing) in the late nineteenth century (Semmingsen, 1954); by most measures, Norway was less mobile than both Great Britain and the United States (Modalsli, 2017). Mobility increased substantially throughout the twentieth century (Modalsli, 2017; Pekkarinen et al., 2017).

2.3 Dams, electricity and economic development

Due to their strong reliance on a steep terrain and flowing water for hydropower production, the placement of hydropower facilities is arguably independent of the distribution of other economic activity. A number of economic studies use this variation in order to disentangle causal relationships between economic development and outcomes of interest. For example, Duflo and Pande (2007) use river gradients to instrument the construction of dams in contemporary India. They find that dams lead to improvement in outcomes downstream due to improved irrigation, and to deterioration upstream.

Kline and Moretti (2014) examine the local effects of "big push" infrastructure development (under the Tennessee Valley Authority in the United States) from the 1930s onward. They find strong local effects on economic growth from such investments. Similarly, Severnini (2014) finds long-run growth effects from dam construction in the United States, while Kitchens and Fishback (2015) find positive effects on rural development due to extensions of the electricity grid in the United States in the 1930s. Moving from general economic growth to more specific studies on the labor market, Gray (2013) finds that electrification in early twentieth-century United States led to an increase in skill demand in white-collar occupations, though not in blue-collar occupations. The present paper shares with these studies the use of electrification as a quasi-independent driver of industrialization, making it possible to disentangle characteristics of local areas from the impacts of industrialization. In this way, we confirm that the observed local effects of industrialization were not limited to the twentieth-century United States, but also existed in early twentieth-century Norway. However, the wealth of Norwegian industrial and population data from the late nineteenth and early twentieth century makes it possible to go further. Thus, we also document that occupational mobility was mainly experienced by workers and families at the low end of the skill distribution. A methodologically related study is the work by de Pleijt et al. (2016). Using the geographical dispersion of steam engines in Great Britain before 1800, they find evidence that industrialization had the effect of increasing demand for at least some types of work-related human capital.

3 Empirical strategies and data

In our data the location of hydropower plants and individuals is recorded at the municipal level. At the time, Norwegian municipalities were small units originally based on church parishes. Local rule was established in Norway in 1837, with 392 municipalities. During the remainder of the nineteenth century, many municipalities split, and by 1900 there were 594 municipalities. The municipalities were responsible for a range of local policies (such as schools and poverty support) and were the basic statistical accounting unit in censuses and other official publications. Urban municipalities (cities) had more extensive responsibilities.

In the period of interest for this paper, there were complete censuses of the Norwegian population in 1891, 1900, 1910 and 1920. Data on population size, employment and sectoral employment shares were published in contemporary reports.[1] To minimize the role of confounding factors, we focus on the rural areas. We omit cities and municipalities adjacent to them from the sample and end up with 455 municipalities.[2] The average 1900 population of these municipalities was 2775 (std. dev.=1741) and the average size

[1]For aggregate municipal data, we make use of digitized data made available by by the Norwegian Center for Research Data (NSD). Further information on the variables can be found in Appendix A. Generally, the analysis of the aggregate population is based on the population above 15 years of age.

[2]There were some changes in municipality borders also after 1900. In the present study, we impose the municipality structure of 1900 but aggregate a few municipalities in order to obtain administrative borders that are stable over time.

was 654 square kilometers. For 1900 and 1910, we have access to full-count records of all individuals resident in Norway; we return to these data below.

3.1 Estimation strategies

The aim of this paper is to understand how the adoption and implementation of a new technology, the use of hydro-electric power, affected workers' occupational mobility. Hydropower usage may have affected some workers directly but may also influence worker outcomes through changes in the local labor market. First, to better understand the sources of change, we investigate whether the adoption of hydropower technology is related to the size of the local labor force and to structural transformation. Let y_{mt} denote the relevant outcomes (labor force size and employment shares in the primary sector, manufacturing and services) in municipality m in a given year t ($t = [1891, 1900, 1910, 1920]$). HP_{mt} is an indicator of hydropower production in the municipality at time t and β_1 our parameter of interest. We estimate the following equation:

$$y_{mt} = \beta_0^1 + \beta_t^1 + \beta_c^1 + \beta_1^1 HP_{mt} + \mathbf{X}_m \boldsymbol{\delta}^1 + \epsilon_{mt}^1 \tag{1}$$

where β_t and β_c represent census and county fixed effects, and $\mathbf{X}_m$ is a vector of municipality characteristics — area size (km^2), and indicators of coast and emigration share.[3] ϵ is an error term assumed to have the usual properties.

Municipalities that are suitable for hydropower production have an unusual geography and topography. These and other natural features of the municipalities might affect factors such as general and agricultural productivity, and housing supply elasticity, which in turn might influence our outcome variables. We therefore include fixed effects for each municipality β_m in Equation (2). The variable of interest is then identified from within variation, removing all biases stemming from observed and unobserved time-invariant characteristics of the municipalities.

$$y_{mt} = \beta_m + \beta_t^2 + \beta_1^2 HP_{mt} + \mathbf{X}_m \boldsymbol{\delta}^2 + \epsilon_{mt}^2 \tag{2}$$

The establishment of hydroelectric plants presents an excellent opportunity to study the local effects of industrialization, as they can only be located in places where the topographical features are right. Nonetheless, there might be places that are more or less suitable owing to natural characteristics. If plant locations are to some extent ruled by strategic decisions, the estimated relationships might be biased. For instance, the hydropower industry and other industries are likely to locate where the most appropriate

[3] To avoid endogeneity, municipal emigration share is computed as the the number of emigrants leaving between period $t-2$ and $t-1$ relative to the population at $t-2$.

supply of labor can be found. A potential unobservable is the stock of human capital in the municipality. A large number of high skilled individuals might attract industries and also affect the future skill composition of the workforce. To deal with endogenous placement issues and potential confounders, we instrument hydropower production status with a measure of hydropower potential. The measure is based on the geographical properties of the municipality and is further described in Section 3.3. We allow hydropower potential z_m to have a different impact in each decade by interacting the measure with census fixed effects. The first stage equation is specified in the following way:

$$HP_{mt} = \beta_m^3 + \beta_t^3 + \alpha_1 z_m \mathbf{1}(1900) + \alpha_2 z_m \mathbf{1}(1910) + \alpha_3 z_m \mathbf{1}(1920) + \mathbf{X}_m \boldsymbol{\delta}^3 + \epsilon_{mt}^3 \quad (3)$$

Second, we use micro data to investigate how hydropower production affected the probability of upward occupational mobility for workers over time and across generations. Individual data are only available for the years 1900 and 1910. Since the upward mobility of workers is dependent on own or father's occupation in 1900 we are left with a cross-section of occupational histories at the individual or "dynasty" (family) level. We cannot include municipality fixed effects because of colinearity. However, we can mitigate the influence of more aggregated area characteristics by adding county fixed effects. The OLS specification resembles Equation (1):

$$y_{im} = \beta_0^4 + \beta_c^4 + \beta_1^4 HP_m + \mathbf{X}_m \boldsymbol{\delta}^4 + \mathbf{X}_i \boldsymbol{\gamma}^4 + \epsilon_{im}^4 \quad (4)$$

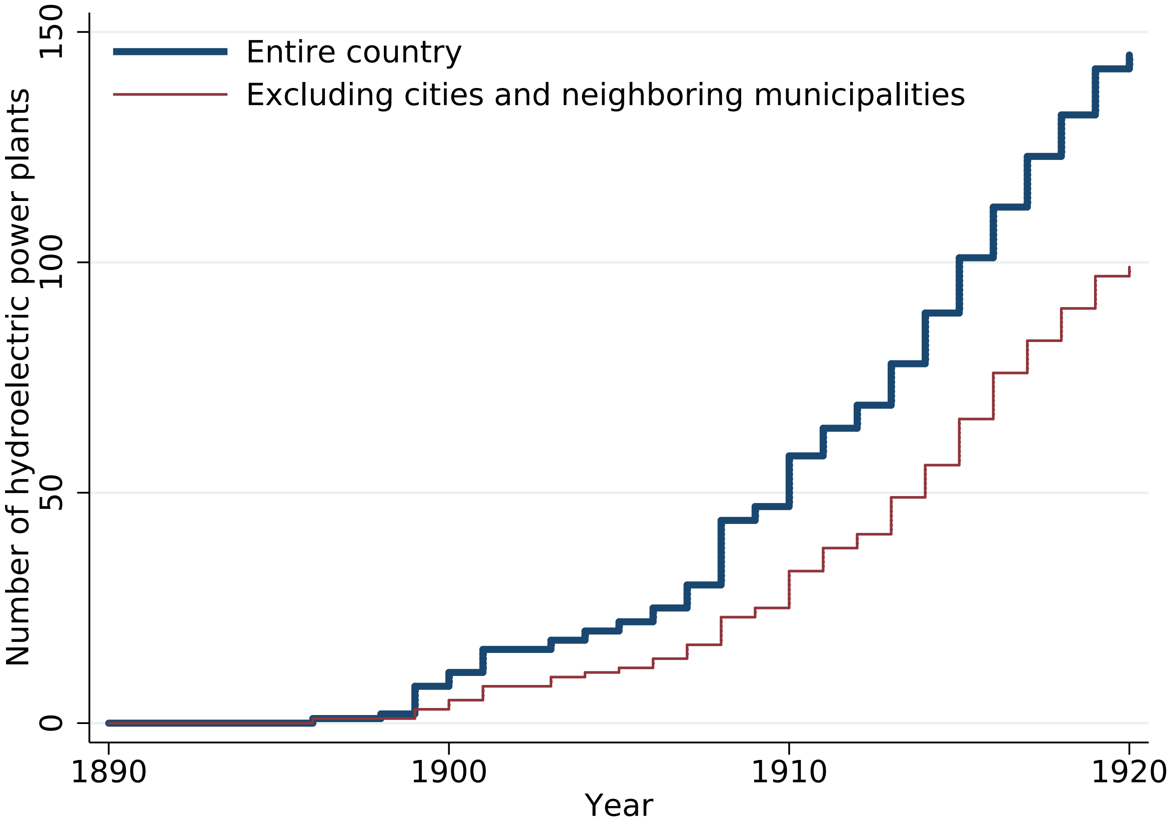
Let y_{im} be an indicator for change in occupation consistent with upward mobility for individual i. We focus on one occupation group at a time. For the linked worker sample, a person observed as a farmer in 1900 but belonging to a manual skilled or white collar occupation in 1910 has a score equal to unity on the upward mobility indicator. For the manual unskilled group upward mobility is also linked to skilled and white collar professions, while for manual skilled workers the only opportunity for advancement is into the white collar level. The same procedure is used on the linked father-son sample, except that father's occupation in 1900 instead of own occupation will be the point of departure.

We omit workers who are resident in a hydropower municipality in 1900. $\mathbf{X}_i$ is a vector of 1900 worker characteristics that includes age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. HP_m is an indicator of hydropower production in municipality of residence in 1910. Further, we instrument hydropower production by hydropower potential in Equation (4), by performing the following first stage estimation:

$$HP_m = \beta_0^5 + \beta_c^5 + \beta_1^5 z_m + \mathbf{X}_m \boldsymbol{\delta}^5 + \mathbf{X}_i \boldsymbol{\gamma}^5 + \epsilon_{im}^5 \quad (5)$$

The instrument is used to correct for endogenous placement of hydropower facilities but

Figure 1: Number of hydropower plants, by year



does not adjust for potential sorting of workers. This issue is pursued further in a sensitivity test where we investigate how movers and stayers are affected by local hydropower usage.

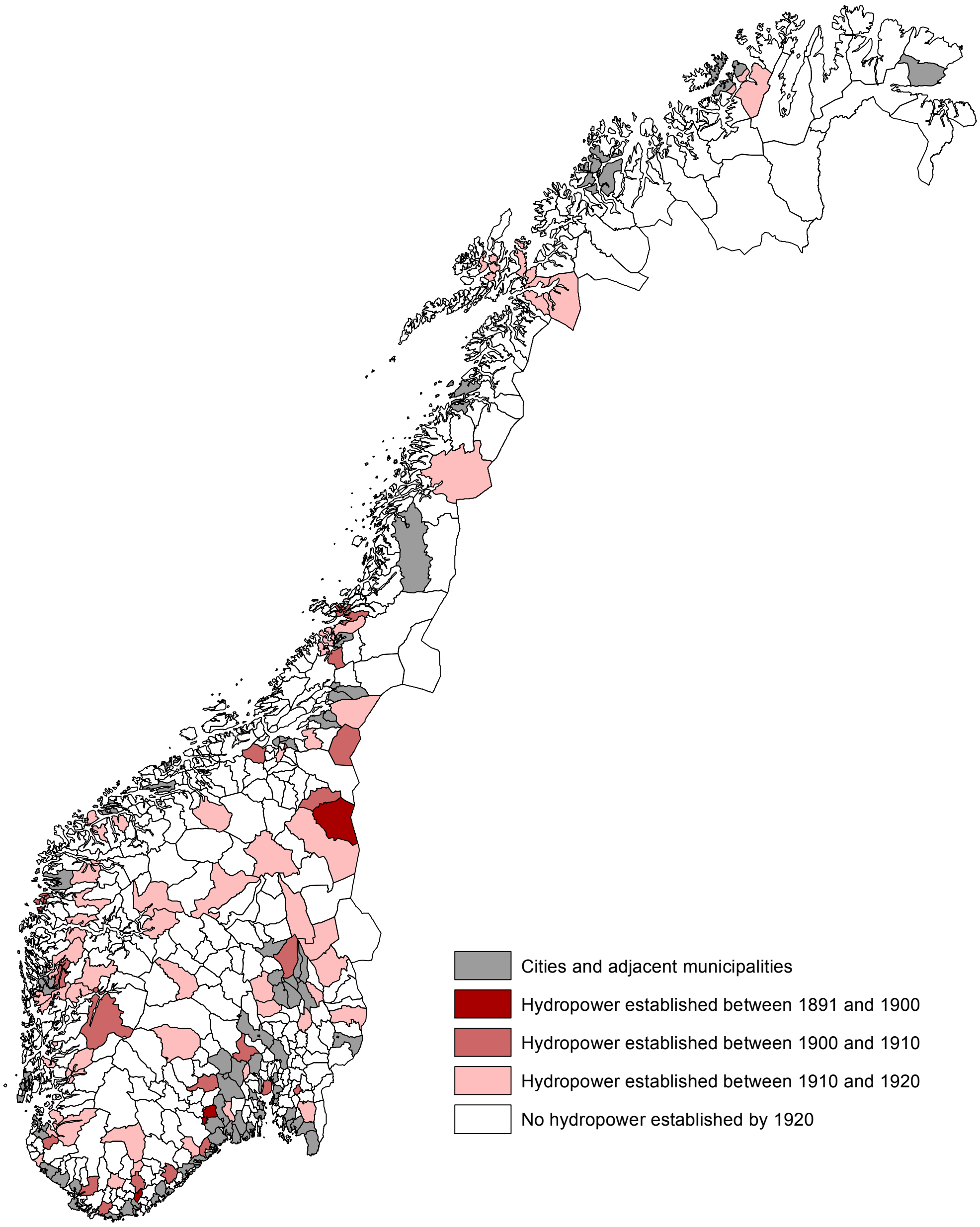
3.2 Data on hydroelectric production

The data on hydropower plants are taken from detailed tabulation published by Norwegian Water Resources and Energy Directorate (1946). The publication provides information on start year and generator capacity. We omit very small plants with generator capacity below 500 kW, as they are not expected to have an effect on the local labor market.[4]

As illustrated in Figure 1, in our sample (which excludes cities and neighboring municipalities) there are 3 power plants in 3 municipalities in 1900, 25 plants in 23 municipalities in 1910 and finally in 1920 there are 97 plants in 74 municipalities. The geographical distribution and start period can be seen in Figure 2. By 1920 the plants are distributed across the entire country.

[4]River power can be used for both mechanical and electrical power, but the record does not make this distinction. We therefore cross-check the list with other historical sources listed in Appendix A.1.

Figure 2: Illustration of hydropower technology adoption in Norway, 1891-1920



3.3 Hydroelectric potential

Our measure of hydropower potential is based on natural characteristics and is similar to the instrument used in Borge et al. (2015). It is defined as follows:

$$HydroPotential_m = \frac{\sum_{v=10}^{v=750}(River4_{vm} \times v)}{Area_m} \tag{6}$$

The hydropower potential of a municipality is determined by the slope of the landscape, water flow and river length. The Norwegian Water and Energy Directorate has classified the national rivers in water volume classes, v.[5] The gradient of each stretch of river is calculated with GIS software using a terrain model with 50 × 50 meter grids obtained from Norway Digital. As in Borge et al. (2015) we only use the river stretches with a gradient of 4 degrees or more. $River4_{vm}$ is the meters of river with water volume class v in terrain with a slope of 4° or more in municipality m. Next, for each river class we multiply the meter of river with the maximum water flow in that class. Finally, we take the sum of these products and divide by the total area (km^2).[6]

Norwegian municipalities vary widely in geographical size. We adjust the measure of hydro potential by the size of the municipality to obtain a scale-independent measure, which does not favor large municipalities. To make sure that the estimated relationships are not directly affected by size, the regressions include area of land in the municipality as a covariate. The measure of hydropower potential in the municipality is time-invariant. By letting hydropower potential have different effects depending on the census year, municipality fixed-effect estimations are feasible.

3.4 Linked micro data

For the censuses of 1900 and 1910, all individual records have been transcribed and made available through a collaboration between the Norwegian National Archives, the Norwegian Historical Data Centre and IPUMS. The records contain information on names, ages, places of residence and occupation (coded in the HISCO standard) of all individuals resident in Norway in those two years.

Using an algorithm that evaluates similarities in name, year of birth and place of birth for all pairs of records in 1900 and 1910, 44 per cent of all men above the age of 25 in 1910 can be linked to a household in 1900. In this way, we can obtain information on an individuals'

[5] The water flow classification has the following categories in cubic meters per second (m^3/s): 1-10, 10-50, 50-100, 100-150, 150-200, 200-250, 250-300, 300-400, 400-600, 600-750.

[6] Municipality borders for the census years are obtained from shapefiles provided by the Norwegian Centre for Research Data (NSD). These are also used to create measures of distance and land area, as well as an indicator of whether a municipality has a coastline.

occupational mobility (change in occupation over these ten years) for older individuals, and intergenerational mobility (comparison between the individuals' occupation and that of their fathers) for younger individuals. The linkage algorithm allows for inaccuracies in the transcription of all fields but discards any potential matches where near-duplicates exist. The process is described in detail in the Online Appendix to Modalsli (2017). The same individual linkage process for the censuses of 1865 and 1900 is used in supplementary analyses.

As a baseline occupation classification, we use the four categories proposed by Long and Ferrie (2013): White collar, Manual skilled, Manual unskilled and Farmers. One way of interpreting the classification is that the first three groups constitute a hierarchy with white collar occupations at the top. Farmers can be thought of as standing beside this occupational ladder, as earnings potential is possibly more related to the characteristics of the farm (which are unobservable in our data) than to human capital. For this reason, we treat mobility into and out of the various occupational categories separately when we discuss occupational mobility in Section 5.

The skilled manual occupations feature a wide range of highly specific occupation titles, and require some sort of training or formal education, while unskilled occupations are often more generic.[7] The farmer group comprises only owner-occupiers and tenants with full legal rights. The linked worker sample is restricted to workers between the ages of 20 and 50 in 1900, while for the linked father-son sample we omit pairs where the son is below 20 or over 40 years old in 1910.

We first examine changes in aggregate employment, before turning to the occupational backgrounds of individual workers.

4 Hydroelectricity and structural transformation

The new technology made it possible to produce electrical power from waterfalls; consequently, some areas attained advantages in production. In the first part of the analysis we will investigate whether municipalities that adopted the new hydropower technology experienced a higher degree of labor force growth and structural transformation. Changes in the local labor force might be determined by both demand and supply factors. We might observe an influx of workers if the local demand for workers exceeds the local supply. Labor market changes will be harder to detect if the new enterprises absorb a local surplus of labor. In the case where workers display low geographical mobility, we might only observe substitution from one sector to another. With new technology and production

[7] Examples of the classification are given in the Appendix, Table A.1. A further disaggregation of manual occupations is discussed in Section 6.

processes, we expect the treated municipalities to shift from primary sector production to manufacturing production. We might also observe shifts towards the service sector if the adoption of hydropower technology caused increased local economic activity of a certain scale.

4.1 Employment shifts towards manufacturing and services

The estimated relationships between hydropower status and labor force size and sectoral employment shares are displayed in Table 1. For each outcome we estimate the relationship on the basis of the three specifications described in Section 3.1 — OLS, municipality fixed effects (FE), and FE with IV-estimation. First, municipalities where hydropower technology is implemented seem to experience a labor force expansion. The OLS and FE models show effect sizes of 43% and 14%, respectively. The coefficient in the FE-model is reduced a third of the OLS-result, when fixed municipality effects are included. The reduction in coefficient size might demonstrate the different potentials for population growth in municipalities with different natural endowments. Furthermore, correcting for endogenous placement of hydropower plants inflates the coefficient to 41 percentage points. The use of instrumental variables may mitigate threats to identification but is only valid under certain conditions. Most crucially, the instrument must not affect the outcome variable directly. Another tradeoff is related to estimate precision, as the estimator inflates standard errors quite markedly. Nonetheless, it is reassuring that the IV-estimate is of the same sign and somewhat comparable in magnitude to the OLS and FE estimates. The positive population growth from hydropower production might suggest an influx of workers such as that described in the Lewis model. Additional analyses in Table B.1 show that the labor force growth in hydropower municipalities favors men somewhat over women.

Second, hydropower production leads to a substantial increase in manufacturing employment share. Again, the inclusion of fixed effects dampens the OLS result, while IV-estimation makes it rebounce slightly. The manufacturing employment share is 3.3 percentage point higher in hydropower municipalities according to the IV-estimate. This amounts to a change of more than half a standard deviation. Third, compared with manufacturing, the change in the employment share in services are smaller with OLS and FE estimation, but larger with IV estimation. When we adjust for biases from municipality heterogeneity and endogenous placement of plants, hydropower production increases the employment share in the service sector by 7.5 percentage points. This is a large effect, but not out of sample, as the maximum value observed for rural municipalities is close to 24 percent of the workforce employed in services.

The greatest employment share change is found in the primary sector. The preferred

Table 1: Hydropower production, labor force size and industry composition

	ln(Labor force size)			Percentage of workers in manufacturing		
	OLS	FE	FE + IV	OLS	FE	FE + IV
	(1)	(2)	(3)	(4)	(5)	(6)
Mean		7.32			9.20	
(std. dev.)		(0.63)			(5.99)	
Hydropower	0.43***	0.14***	0.41***	8.72***	2.66***	3.31*
	(0.06)	(0.02)	(0.06)	(0.88)	(0.63)	(1.96)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	21.46	-	-	21.46
Adjusted R-squared	0.31	0.97	-	0.25	0.74	-
N	1820	1820	1820	1820	1820	1820
	Percentage of workers in services			Percentage of workers in primary sector		
	OLS	FE	FE + IV	OLS	FE	FE + IV
	(7)	(8)	(9)	(10)	(11)	(12)
Mean		3.65			39.1	
(std. dev.)		(2.53)			(8.72)	
Hydropower	1.59***	0.66***	7.51***	-10.35***	-4.07***	-11.47***
	(0.32)	(0.25)	(0.78)	(1.01)	(0.69)	(1.71)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	21.46	-	-	21.46
Adj. R-squared	0.41	0.72	-	0.35	0.77	-
N	1820	1820	1820	1820	1820	1820

Data: Norwegian censuses from 1891, 1900, 1910 and 1920.

Dependent variables: natural logarithm of the labor force size (inhabitants 15 years and older) in columns (1)-(3), percentage worker shares in manufacturing, services and primary sectors in columns (4)-(12). Data on sectoral affiliation are available for people aged 15 and older and present at the census count. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicators of coast and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

specification suggests a decrease of 11.5 percentage points in the sectoral employment share in the primary sector from establishing hydropower production. Overall, the results suggest hydropower-induced structural transformation with a decline in the primary sector, while the manufacturing and service sectors increase in relative size.[8] As we look at relative changes from low levels, moderate absolute changes are translated into sizeable effects. Using level values of the dependent variables in Table B.3, we find that growth in the manufacturing employment is highly significant. Moreover, the number of workers in the primary sector does not change as a result of establishing hydropower production. All in all, the evidence suggests that the introduction of hydropower production has a profound effect on the complexity of the local economy. In the span of a decade, the new technology transforms remote rural economies by attracting workers and facilitating the establishment of industries and services.

5 Occupational mobility in hydropower municipalities

5.1 Upward occupational mobility over careers and generations

The previous section illustrates how the adoption of hydropower technology in early 20th century Norway was linked to employment growth and faster structural transformation at the local level. Before this second wave of industrialization, the mostly agrarian economy of rural areas gave little opportunity for occupational mobility. That might have changed with the hydroelectricity technology breakthrough, adoption of these techniques, and concomitant industrialization process.

Panel A of Table 2 shows the estimated probability of upward occupational mobility for three aggregate occupation groups. We compare an individual's stated occupation in the 1900 census with the occupation stated in the 1910 census. For farmers and unskilled workers we define "upward mobility" as transitioning to a skilled manual occupation or a white-collar occupation; for skilled manual workers we count transitions into white-collar occupation only.

In the OLS estimations, the farmers and unskilled workers display a higher propensity for upward occupational mobility as a result of hydropower production in the municipality. Adopting hydropower technology corresponds to a 6 percentage point higher probability of upward mobility for farmers. The estimated relationship is stronger for the unskilled manual workers, with 18 percentage points greater mobility. It is not surprising that

[8] The results are robust to including the city municipalities in the sample in Table B.2. We also carry out simple suggestive synthetic control estimations and arrive at similar conclusions in Appendix B.1.

Table 2: Relationship between hydropower production and upward mobility for different occupation groups

		Up from farmer		Up from unskilled		Up from skilled	
		OLS	IV	OLS	IV	OLS	IV
		(1)	(2)	(3)	(4)	(5)	(6)
Mean	Panel A	0.05		0.13		0.05	
(std. dev.)		(0.22)		(0.33)		(0.23)	
	Panel B	0.23		0.27		0.08	
		(0.42)		(0.44)		(0.28)	
Panel A: Linked worker sample							
Hydropower		0.06***	0.04	0.18***	0.21***	0.01*	-0.03
		(0.02)	(0.05)	(0.03)	(0.08)	(0.01)	(0.02)
First stage F-value		-	21.63	-	42.76	-	41.70
Adjusted R-squared		0.02	0.02	0.04	0.04	0.01	0.00
N		32904	32904	30824	30824	16193	16193
Panel B: Sample of linked father-son pairs							
Hydropower		0.22***	0.02	0.24***	0.39***	0.04***	-0.06
		(0.03)	(0.08)	(0.03)	(0.13)	(0.01)	(0.05)
First stage F-value		-	25.22	-	18.43	-	26.64
Adjusted R-squared		0.06	0.04	0.06	0.06	0.01	-0.00
N		32771	32771	10542	10542	5198	5198

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from the linked worker sample, while Panel B shows results from the linked father-son sample.

Dependent variables: In columns (1)-(2) the dependent variable is an indicator of change in profession from farmer to skilled and white collar between 1900 and 1910. In columns (3)-(4) it is an indicator of change in profession from unskilled to skilled or white collar between 1900 and 1910, while in columns (5)-(6) it is an indicator of change in profession from skilled to white collar between 1900 and 1910. In the regressions we control for the following 1900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and indicator of not having residency in municipality of birth. All regressions include indicators of coast, area of land, share of emigrants in the decade preceding 1900 and county fixed effects.

Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

farmers have lower mobility than unskilled workers. For farmers, the ownership and rents of land is presumably a disincentive for occupational movement. For those who do not own land, including agricultural and other unskilled workers, there appears to be greater willingness to explore new employment opportunities.

The coefficient for skilled manual occupations is small, which strengthens the interpretation that the results reflect increased employment in manufacturing and services, rather than a more general shift to higher-status occupations.[9]

As mentioned earlier, the endogenous placement of hydropower plants due to unobserved factors is a concern. To mitigate the influence of confounders we instrument hydropower status in the residence municipality of 1910 with hydropower potential. With instrumental variable estimation, the unskilled workers are the only occupation group with a significant effect. The point estimate of hydropower plants for the unskilled manual workers increases slightly, by 3 percentage points, to 21 in the IV specification. However, the standard errors are also inflated, so that the OLS and IV estimates are not significantly different.

Mobility may decrease with worker experience, as occupation-specific human capital is accumulated. Focusing on workers' occupational transitions may thus lead to underestimation of the mobility changes taking place in industrializing hydropower municipalities. To capture a fuller picture, we also investigate occupational mobility across generations; that is to say, whether the sons display upward occupation mobility relative to father's occupation. We expect intergenerational mobility to be less restricted by the timing of treatment and, consequently, we expect the coefficients to be higher. As can be seen from Panel B of Table 2, that is the case. All groups show a positive likelihood of upward intergenerational mobility in hydropower municipalities in the OLS specification. The coefficients for sons of farmers and unskilled manual workers are 22 and 24 percentage points, respectively. Sons of skilled workers have a small positive result of 4 percentage points.

Instrumenting hydropower status, only sons of manual unskilled workers have a positive likelihood of upward intergenerational mobility. The results for sons of farmers and skilled manual workers are not significant at conventional levels. We will therefore pay less heed to these groups in the following. The probabilities of upward intergenerational mobility for sons of unskilled workers are 39 and 24 percentage points with IV and OLS estimation, respectively. The IV estimate is therefore about 60 percent higher. However, the standard error is more than quadrupled. A potential explanation for the discrepancy between the IV and OLS estimates is that the compliers of the instrument reside in remote rural areas with challenging geography and, therefore, scant initial economic activity. This might translate into a higher mobility potential in these municipalities that is triggered when

[9]Generally, the conclusions from all the analyses on upward mobility hold when using a specification with number of hydropower plants in the municipality instead of hydropower status.

new industries are established.

The upward occupation mobility of unskilled workers in hydropower municipalities may be related to increased skill demand. Goldin and Katz (1998) demonstrated a positive relationship between formal skills and worker outcomes in the United States, more or less in the same time period as our study. In contrast, Norwegian workers had a low level of formal training, though a high level of basic human capital (reading and writing skills). This may explain the relatively rapid adjustment in the course of the decade, if other specific skills could be obtained by means of on-the-job training.

5.2 Sensitivity tests

There are several ways in which we can investigate whether the results in Table 2 are driven by spurious correlations. Table 3 presents the results of a battery of robustness checks.

First, we consider whether there are insufficient controls for underlying municipality differences. The instrument is based on river gradient and water flow, which might be correlated with the general gradient and precipitation in the municipality. These municipality characteristics might affect productivity and upward occupational mobility. In the IV specification in Column (1) we control for measures of average gradient and precipitation, effectively identifying changes in hydropower status from river features conditional on general municipality geography. The effects are robust to these inclusions.

Infrastructure has been related to skill demand and can therefore affect the likelihood of upward mobility. For instance, Michaels (2008) finds that infrastructure investment, the construction of the interstate highway system in the United States, leads to increased trade and greater demand for skilled workers in manufacturing. In columns (2) and (3) we include variables describing 1800 municipal infrastructure items: diligence stops, railway stations, and ship and steamboat routes. The data were observed quite some time prior to the period we are investigating. Infrastructure is likely to persist, however. The inclusion of the historical infrastructure variables does not change the results much.

Because of the data structure we are not able to observe directly whether or not hydropower-adopting municipalities displayed a positive pre-treatment trend. We are, however, able to test the impact of historical intergenerational mobility on the results. With micro data for the year 1865, we can calculate intergenerational mobility between 1865 and 1900, using the father-son matching procedure. For each skill group and municipality, we calculate the average likelihood of upward mobility. This variable is then included in columns (4) and (5) of Table 3. All panels show that historical intergenerational mobility is positively correlated with the 1910 outcomes. The estimated coefficients of upward mobility fall for all specifications, and the IV-specification for unskilled manual workers is not robust to this inclusion.

The propensity for upward mobility might be different for locals and newcomers; for instance, locals might have established networks that can assist in job search. We conduct the analysis by changing the dependent variable to be conditional on moving or staying in columns (6)-(9). We also include a variable indicating whether the individual is a mover (e.g. changes municipality of residence between the two census years). All specifications provide positive propensities for upward mobility from hydropower production in the municipality of residence of 1910. The exception is the results for propensity for intergenerational upward mobility for movers. The interpretation of the coefficients for movers is complicated because of sorting, as the likelihood of advancement might be taken into account in the relocation decision. There is also a possibility that some workers are forced to move because of scarce job opportunities in the home region. However, the relationship between upward mobility and hydropower production is not merely an artifact of sorting, as stayers do also display upward mobility.[10]

[10]The results are similar when the sample is split into two subgroups: movers and stayers.

Table 3: Upward mobility for unskilled workers in hydropower municipalities. Sensitivity of results

	Slope and precipitation	Infrastructure		Pre-trend in mobility		Upward mobility conditional on staying		moving	
	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: unskilled manual workers from the linked worker sample									
Hydropower production	0.24***	0.18***	0.19**	0.10***	0.03	0.04***	0.12***	0.09***	0.07*
	(0.08)	(0.03)	(0.08)	(0.02)	(0.08)	(0.01)	(0.04)	(0.02)	(0.04)
Intergenerational mobility, 1865-1900				0.47***	0.49***				
				(0.02)	(0.04)				
First stage F-value	49.78	-	38.82	-	37.32	-	40.21	-	40.21
Adjusted R-squared	-	0.04	-	0.09	-	0.03	-	0.30	-
N	30824	30824	30824	29026	29026	30824	30824	30824	30824
Panel B: sons of unskilled manual workers from the linked father-son sample									
Hydropower production	0.38***	0.24***	0.31**	0.12***	0.24*	0.06***	0.44***	0.11***	-0.06
	(0.12)	(0.03)	(0.12)	(0.02)	(0.13)	(0.02)	(0.13)	(0.02)	(0.08)
Intergenerational mobility, 1865-1900				0.70***	0.66***				
				(0.04)	(0.05)				
First stage F-value	23.10	-	18.25	-	14.85	-	17.86	-	17.86
Adjusted R-squared	-	0.07	-	0.14	-	0.09	-	0.43	-
N	10542	10542	10542	10136	10136	10542	10542	10542	10542

Data from Norwegian censuses of 1900 and 1910. Panel A displays results for the unskilled manual workers in the linked worker sample, while Panel B shows results for unskilled manual workers in the linked father-son sample. In Column (1), we control for the share of land with slope more than 4 degrees and average millimeters of precipitation in the municipality. In columns (2)-(3), the specification includes indicators of steamboat and ship routes, railway stations and diligence stops in the municipality, while in columns (4)-(5) historical intergenerational mobility (1865-1900) is added. In columns (6)-(9) the dependent variable is upward mobility conditional on being a mover (changing municipality of residence between the two census years) or stayer. In the regressions we control for the following 1900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and indicator of not being resident in municipality of birth. All regressions include an indicator of coast, area of land, share of emigrants in the decade preceding 1900 and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

5.3 Regional heterogeneity and treatment intensity

Table 4: Treatment intensity. Analyses for sub-samples of treated municipalities

	Hydropower by 1920	Treatment intensity in megawatts			
		10 MW	MW/km2	MW/population in 1900	MW/population density
	(1)	(2)	(3)	(4)	(5)
Panel A: unskilled manual workers from the linked worker sample					
Hydropower production	0.12***				
	(0.03)				
Megawatt treatment		0.01	1.12**	-4.14	0.02**
		(0.02)	(0.54)	(7.41)	(0.01)
County fixed effects	Y	N	N	N	N
Adjusted R-squared	0.08	0.05	0.07	0.05	0.05
N	6005	2535	2535	2535	2535
Panel B: sons of unskilled manual workers from the linked father-son sample					
Hydropower production	0.18***				
	(0.04)				
Megawatt treatment		0.05**	2.60***	11.90	0.02**
		(0.02)	(0.39)	(8.13)	(0.01)
County fixed effects	Y	N	N	N	N
Adjusted R-squared	0.10	0.03	0.12	0.02	0.03
N	2075	1007	1007	1007	1007

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from the unskilled manual workers in the linked worker sample, while Panel B shows results for unskilled manual workers from the linked father-son sample. The dependent variables are upward mobility for the relevant occupation groups. In Column (1) the sample consists of workers in municipalities that get treatment in 1910 and 1920. In columns (2)-(5) the sample is reduced to workers in treated municipalities and the variables of interest are measures of treatment intensity based on megawatts produced in the municipality. In the regressions we control for the following 1900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. All regressions include an indicator of coast, area of land and share of emigrants in the decade preciding 1900.

Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Alternative tests of the estimates' robustness can be performed by imposing sample restrictions and investigating how the effects vary with treatment intensity. In Column (1) of Table 4 we restrict the sample to the municipalities that obtain hydropower technology between 1900 and 1920. Future hydropower municipalities are then used as a control group, which should resemble the other hydropower municipalities to a large degree. The results remain robust for both specifications, although the coefficients are somewhat smaller, ranging from 12-18 percentage points.

Using a publication by Den kgl. Vandfalkommission (1914), we are able to allocate power production (megawatt) in 1914 to all but 5 hydropower plants. We restrict the sample to municipalities with positive values of produced power in columns (2)-(5). We experiment with different specifications of the variable based on megawatt produced in 1914. This is a strict test as it reduces the sample size considerably, but a positive result would ease our concern that unobserved regional heterogeneity might affect the result. For the linked worker sample, MW relative to municipality size and municipality population density in 1900 yields positive results. There therefore seem to be localization effects, as proximity to high production increases the propensity to advance. Using the linked father-son sample and also using the raw megawatt variable provides positive results. However, for neither sample is the number of megawatts relative to population significant.

5.4 Timing of plant opening

The results presented so far are measured only in 10-year intervals, as there is no comprehensive record of the population between census years. However, using the annual resolution of the hydropower plant data, we can gain some insight into the timing of the changes in the labor market in response to the development of new plants.

Table 5: Timing of hydropower adoption and the likelihood of upward mobility

Plant opening	1900-1903 (1)	1904-1906 (2)	1907-1909 (3)	1910-1912 (4)
Panel A: unskilled manual workers, linked worker sample				
Hydropower production	0.14***	0.31***	0.06**	0.04***
	(0.03)	(0.06)	(0.03)	(0.02)
Adjusted R-squared	0.03	0.04	0.02	0.02
N	29586	29640	29866	29134
Panel B: sons of unskilled manual workers, father-son sample				
Hydropower production	0.21***	0.40***	0.07*	0.08***
	(0.05)	(0.05)	(0.04)	(0.02)
Adjusted R-squared	0.05	0.07	0.05	0.05
N	10031	10129	10104	9861

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from unskilled manual workers from the linked worker sample, while Panel B shows results for sons of unskilled workers using the linked father-son sample. Dependent variables: indicators of upward mobility. Variable of interest: indicator of hydroproduction in the years in question. Estimator: OLS.

In the regressions we control for the following 1900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. All regressions include an indicator of coast, area of land, share of emigrants in the decade preceding 1900, and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The record does not provide information on when the construction of hydropower plants started, we only know the first year of operation. If we assume that plants were constructed rather rapidly, we still cannot observe how the local labor markets are affected by signals and expectations of a booming economy. Therefore, we may underestimate the upward mobility in hydropower municipalities of workers positively affected before occupation was observed in 1900. In addition, workers treated late in the period have shorter exposure time and are therefore less likely to display occupational changes. Both timing effects provide a downward bias, suggesting that we estimate a lower bound for the effects. This notion is supported by the results in Table 5. In columns (1)-(3) we allocate treatment based on the opening years of the plants and exclude observations that receive treatment earlier and/or later in the 1900-1909 period. The variable of interest is then an indicator equal to unity if plants where opened in a given period. As there are few treated municipalities, we conduct the analyses with simple OLS and not IV-estimation. Although all specifications provide positive and significant results, the occupation groups have a higher effect of treatment in the middle period (1904-1906) compared to the other two periods. In Column (4) the variable of interest is given as treatment in the years immediately after 2009. Here, too, we see a positive coefficient, suggesting that the construction of hydropower plants or signals of improving economic conditions lead to changes in local labor markets.

6 Does upward occupational mobility cause a hollowing out of the skill distribution?

We observe that upward occupational mobility is experienced most strongly by individuals at the low end of the occupational distribution. This is in line with the results of Goldin and Katz (1998) using United States data for the early 20th century, showing that technology has a skill bias. Recent works have found that technology contributes to a hollowing out of the occupation distribution (Gray, 2013; Katz and Margo, 2014). We investigate whether this is also the case for Norway in the early twentieth century. Using the Duncan Socioeconomic Index (SEIUS) we obtain an indicator variable for the socioeconomic status of each occupation. Based on these values, we split the sample of manual workers into five skill classes.[11] The classes are defined so as to make the five categories as similar in size as possible, and are further described in the Appendix (Section A.3).

The hollowing out of the occupation structure is evident when we investigate changes in detailed occupational shares in Table 6. The lowest- and highest-skilled groups increase in size from the time of the establishment of hydropower plants. The other groups are unaffected or decline in size, however.

We also investigate how the mobility responses to the new technology differ across the skill distribution. As can be seen from Panel A in Table 7, the upward mobility in hydropower municipalities is experienced by workers in the middle of the skill distribution. Specifically,

[11]The SEIUS indicator is based on typical income and education scores for each occupation, based on U.S. data from the mid-twentieth century. The crosswalk between HISCO occupations and SEIUS scores was obtained from micro data from the North Atlantic Population Project.

Table 6: Hydropower adoption and change in manual worker occupational shares

	Lowest-skilled (1)	Low-skilled (2)	Medium-skilled (3)	High-skilled (4)	Highest-skilled (5)
Mean	20.58	55.89	11.96	1.68	9.89
(std. dev.)	(11.87)	(17.93)	(8.92)	(1.79)	(6.97)
Hydropower	3.67***	-6.19***	0.99	-0.96	2.49***
	(1.07)	(1.81)	(1.10)	(0.70)	(0.96)
Adjusted R-squared	0.31	0.33	0.21	0.02	0.10
N	452	452	452	452	452

Data: The Norwegian censuses of 1900 and 1910 are used to create a linked sample of workers belonging to detailed occupational categories. Estimator: OLS.

Dependent variables: change in detailed occupational shares between 1900 and 1910, in percent. The five occupation classes are derived using the SEIUS measure. The measure ranks occupations using United States data on income and education from 1950. The classes have the following cutoffs: 9, 15, 20 and 25. The mean and standard deviation for 1900 are provided in the top panel. The variable of interest is hydropower status in 1910. Municipalities that received this status earlier are omitted. In the regressions we include an indicator of coast, area of land, share of emigrants in the decade preceding 1900, and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Hydropower adoption and the likelihood of upward mobility for manual workers in different skill classes

	Lowest skilled (1)	Low skilled (2)	Medium skilled (3)	High skilled (4)
Panel A: unskilled manual workers from the linked worker sample				
Hydropower production	0.03*	0.07***	0.04***	0.02
	(0.02)	(0.02)	(0.01)	(0.03)
Adjusted R-squared	0.04	0.02	0.02	0.01
N	17329	46708	11460	1622
Panel B: sons of unskilled manual workers from the linked father-son sample				
Hydropower production	0.16***	0.19***	0.09***	0.08
	(0.04)	(0.03)	(0.03)	(0.05)
Adjusted R-squared	0.16	0.05	0.03	0.03
N	2405	40958	3648	463

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from the linked worker sample, while Panel B shows results from the linked father-son sample. Dependent variables: upward mobility indicators for manual workers in five different skill classes. The skill classes are derived using the SEIUS measure. The measure ranks occupations using US data on income and education from 1950. The classes are based on the following cutoffs: 9, 15, 20 and 25.

In the regressions we control for the following 1900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. All regressions include an indicator of coast, area of land, share of emigrants in the decade preciding 1900 and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

the low- and medium-skilled groups have a propensity for upward mobility of 7 and 4 percentage points, respectively, due to the change in hydropower production status. This might suggest a skill biased response that hollows out the occupation structure.

The same general pattern is found in Panel B when investigating intergenerational mobility. However, in addition to the sons of the low- and medium-skilled families, the sons of the lowest-skilled also experienced upward mobility. The estimate is once more highest for the low-skilled with a point estimate of 19 percentage points. The lowest-skilled group has a propensity of 16 percentage points, while the medium-skilled group has a propensity of 9 percentage points. In accordance with analyses presented earlier in this paper, the estimated coefficients are higher for the father-son sample than for the linked worker sample. The conclusions are similar when the OCSCORUS measure based solely on income is used (See Table B.4). With the OCSCORUS measure, the positive propensity for upward mobility is present for all occupation groups, but effects for the those in the middle of the distribution are stronger.[12]

7 Concluding remarks

As technological change often takes place gradually, it is demanding to identify and quantify how technology change affects local economic conditions and workers of different backgrounds and skills. These questions are of great importance for understanding both the historical and the modern setting, and for forecasting what to expect in the future. This paper contributes by providing new evidence on the impact of the adoption of hydropower technology on local outcomes in Norway in the period 1891-1920. Few studies investigate this impact outside the setting of the core industrializing countries or focus on such an early period. Norway is a suitable setting for such a quasi-experiment, as the country had undergone limited industrialization, the hydropower technology breakthrough was abrupt, and only some municipalities had natural features that lent themselves to the introduction of the technology.

The relationship between industrialization and the implementation of hydropower technology in Norway has previously been described only using national-level data. With our regional perspective, we find that the industrialization process is not distributed equally across the country and that hydropower municipalities experience local employment growth and structural transformation. Specifically, the manufacturing and service sectors grow at the expense of the agrarian sector. The results are in line with those of Kline and Moretti (2014) and Severnini (2014) who find growth effects of local investments. The present paper also demonstrates that the effect had an equalizing social

[12]Changes in the skill distribution might also stem from workers experiencing downward mobility. If anything, this is less likely in hydropower municipalities, as can be seen from Table B.5.

gradient (lifting individuals from lower-skilled into higher-skilled occupations).

The findings indicate that hydropower technology adoption and the concomitant industrialization process led to upward mobility of workers and families at the low end of the skill distribution. The general picture is that manual unskilled workers experienced upward occupational mobility and sons of unskilled workers experienced upward intergenerational mobility. Focusing on the finer skill categories of manual workers appears to reveal a hollowing out of the skill distribution in hydropower municipalities. The skill groups at the ends of the distribution increase in size while those in between are unaffected or decrease.

The results place industrial development in early twentieth-century Norway firmly in the skill-bias category, similar to the more industrially developed United States in the same period, rather than in the unskilled-biased framework of nineteenth-century Great Britain. Acemoglu (2002) argues that the difference between the two can partly be explained by the general skill level in the population, with British cities having a large reserve of unskilled workers. In 1900, there was not yet a large manufacturing sector in Norway, and the Norwegian labor force had a high share of farmers and unskilled laborers, making it superficially similar to other countries earlier in the industrialization process. However, there was a comprehensive elementary-school system and likely a high level of latent human capital in the population (Sandberg, 1979). One possible reconciliation of the facts is that the changing occupational distributions reflect a reallocation of a skilled labor force from unskilled to skilled occupations — that is, a reserve army of skilled workers, or at least workers who could receive on-the-job training to better cope with the new technology.

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A Data details

A.1 Hydropower production

The data on hydroelectric power plants is mainly taken from a detailed tabulation published by the Norwegian Water Resources and Energy Directorate (1946). The source does not distinguish between mechanical and electrical generators. In general, this would give a too early start year since mechanical generators were already in use when electrical hydropower generators were introduced. To ensure that the source is reliable we cross-check the information against other historical accounts. The following supplementary sources were used:

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Fosselv power stations 1 and 2 are counted as one plant. The two power stations have the same owners and start-up year. The same applies to the upper and lower power stations at Hønefoss.

A.2 Sector composition data for municipalities

The data on sector composition between 1891 and 1920 are taken from the Norwegian Center for Research Data, NSD. The data collection and reporting become more detailed with each census. For instance, the 1910 census differentiates between rural and urban municipalities, while the 1920 census also distinguishes between the sexes. That means that the categories for the oldest census used, 1891, determine the grouping of professions in each sector. The data are reported for individuals aged 15 years or older and present at the count. We distinguish between three sectors: primary sector, manufacturing and services.

A.2.1 Primary sector

The following categories comprise the primary sector in each census:

Census year	Rural/ urban	Category
1865	Rural	Farming and animal husbandry, forestry, fisheries: main persons
		Farming and animal husbandry, forestry, fisheries: servants
	Urban	Farming and animal husbandry, forestry, fisheries: main persons
		Farming and animal husbandry, forestry, fisheries: servants
1891		Farming and animal husbandry, horticulture, forestry and hunting, fisheries, log driving
1900		Sedentary agricultural sectors including forestry and hunting, fisheries
1910	Rural	Farming and animal husbandry: farmers, landowners
		Farming and animal husbandry: tenant farmers
		Farming and animal husbandry: children living at home, etc.
		Farming and animal husbandry: servants
		Farming and animal husbandry: other agricultural laborers
		Forestry and hunting: forest workers
		Farming and livestock breeding, forestry: others
		fisheries: independent fishers
		fisheries: others
	Urban	Farming, animal husbandry, forestry
		Fisheries: independent fishers
		Fisheries: others
1920	Rural	Farming, horticulture and forestry: farmers, landowners
		Farming, horticulture and forestry: tenant farmers
		Farming, horticulture and forestry: children living at home occupied by farming and livestock breeding
		Farming, horticulture and forestry: servants at farms
		Farming, horticulture and forestry: other independent laborers
		Farming, horticulture and forestry: clerks
		Farming, horticulture and forestry: forest workers, log drivers
		Farming, horticulture and forestry: other workers in farming and horticulture
		Fisheries
	Urban	Farming, horticulture and forestry
		Fisheries

A.2.2 Manufacturing sector

The following categories comprise the manufacturing sector in each census:

Census year	Rural/ urban	Category
1865	Rural	Mining and manufacturing industry: main persons
	Urban	Mining and manufacturing industry: main persons
1891		Manufacturing industry, mining and quarrying industry, peat and ice harvesting
		Artisan industries
		Mining industries
		Quarrying and harvest of ice and peat
1900		Manufacturing industry, mining and quarrying industry etc.
		Artisan industries
		Other industries
1910	Rural	Manufacturing industry, mining and quarrying industry
		Artisan industries
		Other smaller industries: works and communications
	Urban	Manufacturing industry, mining and quarrying industry
		Artisan industries
		Other smaller industries: works, communications and others
		Other smaller industries: textile
1920	Rural	Manufacturing industry
		Artisan industries
		Mining and quarry industry, peat harvest etc.
		Construction work
	Urban	Manufacturing industry: factory owners etc.
		Manufacturing industry: clerks etc.
		Manufacturing industry: laborers
		Construction workers

A.2.3 Service sector

The following categories comprise the service sector in each census:

Census year	Rural/ urban	Category
1865	Rural	Trade: Main persons
		Transport (excluding sea transport), post and telegraph: main persons
		Profession work: main persons
	Urban	Trade: merchants, shipowners: main persons
		Trade: sales assistants: main persons
		Trade: workers: main persons
		Trade: liquor and ale merchants, peddlers: main persons
		Trade: sales assistants and workers selling liquor and ale: main persons
		Transport (excluding sea transport), post and telegraph: main persons
		Profession work: main persons
1891		Trade and banking
		Hotels and restaurants
		Transportation: trains and land-carriage
1900		Trade, banking and transportation (excluding sea transport)
		Public sector and private professional work
1910	Rural	Trade, banking and transportation
		Trade: sales assistant
		Profession work
	Urban	Trade: Merchants, wholesalers
		Trade: Sales assistant
		Trade, banking and transportation: others
		Profession work
1920	Rural	Trade activity
		Transportation: Carriers, chauffeurs etc. (excluding sea transport)
		Train, post and telegraph etc.
		Profession work
	Urban	Trade: Merchants, wholesalers
		Trade: Clerks
		Trade: Sales assistant, messengers
		Banking, insurance, brokers, etc.
		Hotels and cafes
		Transportation: Carriers, chauffeurs etc. (excluding sea transport)
		Train, post and telegraph etc.
		Profession work

A.3 Occupational classification

The occupational categories used in the baseline analysis are shown in Table A.1. Percentages refer to the share of the male population aged 20-50 in 1910.

In Section 6, a more fine-grained classification of the manual occupations is used, based on the SEIUS classification (as implemented by NAPP). The cutoffs were chosen on the basis of the number of individuals in each occupation, to create categories as similar in size as possible. By way of illustration, the largest occupation groups are shown with

SEIUS rankings and categories in Table A.2.

Table A.1: Occupational classifications, and share of total population (men age 20-50, 1910)

Category	Share of population
White collar	
HISCO: 1100-3100, 3250-6400, 7110, 7600-13300, 14120-16300, 17120-22190, 23160, 31010-36020, 37020-45120, 45220-49030, 51020-51030, 51050-51090, 58500, 59200, 59950, 63220, 77630, 89500, 94920	
Largest categories:	
Dealer, merchant etc. (wholesale and retail trade)	2.2%
Salespeople, wholesale or retail trade	1.0%
Office clerks, specialization unknown	0.8%
Teachers (primary)	0.7%
Ship's navigating officers and ship's mates	0.7%
Other occupation categories	8.1%
Manual skilled	
HISCO: 3210-3240, 6500, 7500, 16400, 23110-23150, 23170-24100, 36040-36090, 45190, 49090, 58100-58220, 58420-58430, 62800, 64970-77620, 77640-89200, 89400, 89620-94290, 94930-96900, 97130, 97150-97300, 97440, 98120-98440, 98510-98730, 99200, 99450	
Largest categories:	
Carpenters	3.1%
Seamen	2.3%
Boot and shoe makers and repairers	1.6%
Sawyers and other titled wood/sawmill operatives	1.6%
Paper mill machine operators and paper makers	1.4%
Other occupation categories	22.0%
Manual unskilled	
HISCO: 7210, 13990, 51040, 52020-57040, 58300, 59100, 59940, 59990, 61115, 61330, 62110-62740, 62920-63140, 63230-64960, 89300, 97120, 97140, 97410-97430, 97490, 98490, 98900-99150, 99300-99440	
Largest categories:	
Farm workers, specialization unknown	6.7%
Fishermen	6.2%
Lumbermen, loggers and kindred workers	2.5%
Husbandmen or cottars	1.9%
Day laborers (e.g., journalier)	1.8%
Other occupation categories	8.0%
Farmer	
HISCO: 61110, 61220-61320, 61400	
Largest categories:	
General farmers and farmers not further specified	18.4%
Farmer and fisherman	4.5%
Other occupation categories	0.4%

Table A.2: Occupational classifications, examples (manual occupations only)

Category (HISCO title)	SEI score	Share of pop.
Highest-skilled (SEI 26 or higher)		
Delivery men and drivers of goods	32	1.0%
Mason not further specifiedor combined	27	1.3%
Mechanics	27	1.6%
High-skilled (SEI 21-25)		
Stone carvers or cutters and stone yard workers	25	1.6%
Tailors and dressmakers	23	1.3%
Bakers	22	1.2%
Medium-skilled (SEI 16-20)		
Carpenters	19	5.3%
Boot and shoe makers and repairers	18	2.8%
Sawyers and other titled wood/sawmill operatives	18	2.6%
Papermill machine operators and paper makers	18	2.4%
Ship's engine men	17	1.7%
Painters, not further specified	16	1.4%
Blacksmiths	16	1.5%
Seamen	16	3.9%
Low-skilled (SEI 10-15)		
Drivers, nec	15	1.7%
Husbandmen or cottars	14	3.2%
Cottar and fisherman	14	1.5%
Ship and boat loaders and dock workers	11	1.1%
Miners	10	1.6%
Fishermen	10	10.5%
Lowest-skilled (SEI 9 or lower)		
Laborers not further specified	8	1.5%
Other skilled railway workers	8	1.4%
Navvies, excavators and diggers, not further specified	8	0.8%
Day laborers (e.g., journalier)	8	3.1%
Road builders, workers and labourers	8	0.9%
Servants not further specified	7	1.3%
Farm workers, specialization unknown	6	11.4%
Lumbermen, loggers and kindred workers	4	4.2%
Porters	4	1.0%

A.4 Summary statistics

Table A.3: Summary statistics for municipality analyses

	Mean	Std. dev.
Labor force size	1828.6	1222.09
Employment share in manufacturing	9.20	5.99
Employment share in services	3.65	2.53
Employment share in primary sector	39.1	8.72
Number of hydropower plants	0.07	0.32
Indicator of coast	0.61	0.49
Area of land	654.25	913.2
Emigration share (lagged)	6.08	5.4

Table A.4: Summary statistics for upward mobility analyses, linked worker sample

	Mean	Std. dev.	N
Indicator of upward mobility for farmers	0.05	0.22	33001
Indicator of upward mobility for unskilled manual workers	0.13	0.33	30923
Indicator of upward mobility for skilled manual workers	0.05	0.23	16268
Number of hydropower plants	0.09	0.34	86730
Age	34.22	8.92	86730
Age squared	1250.85	622.54	86730
Indicator of being married	0.62	0.48	86432
Number of children	1.91	2.28	86730
Indicator of not having residency in municipality of birth	0.22	0.41	86730
Indicator of coast	0.62	0.49	86730
Area of land	677.86	805.83	86730
Emigration share (lagged)	4.33	3.22	86730

Table A.5: Summary statistics for upward mobility analyses, linked father-son sample

	Mean	Std. dev.	N
Indicator of upward mobility for farmers	0.23	0.42	32864
Indicator of upward mobility for unskilled manual workers	0.27	0.44	10588
Indicator of upward mobility for skilled manual workers	0.08	0.28	5213
Number of hydropower plants	0.1	0.38	50999
Age, son 1900	16.79	5.4	50999
Age squared, son 1900	311.01	201.84	50999
Indicator of son being married	0.02	0.14	50834
Sons number of children	0.02	0.19	50999
Indicator of son being born in resident municipality	0.09	0.28	50999
Indicator of coast	0.62	0.49	50999
Area of land	674.78	803.83	50999
Emigration share (lagged)	4.27	3.21	50999

B Robustness analyses

Table B.1: The effect of hydropower production on the labor force size by gender.

	ln(Labor force size)		
	All	Men	Women
	IV	IV	IV
	(1)	(2)	(3)
Hydropower plants	0.41***	0.49***	0.33***
	(0.06)	(0.07)	(0.06)
Municipality fixed effects	Y	Y	Y
First stage F-statistics	21.46	21.46	21.46
Adjusted R-squared	0.96	0.94	0.96
N	1820	1820	1820

Data: Norwegian censuses from 1891, 1900, 1910 and 1920.

Dependent variables: Natural logarithm of the labor force size. Overall labor force size is in Column (1), and labor force size by gender are in columns (2)-(3). Regressions control for year fixed effects, municipality fixed effects, geographical size of municipality (km^2), indicator of coast and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table B.2: Hydropower production, labor force size and industry composition. Sample with urban municipalities included

	ln(Labor force size)			Percentage of workers in manufacturing		
	OLS	FE	FE + IV	OLS	FE	FE + IV
	(1)	(2)	(3)	(4)	(5)	(6)
Mean (std. dev.)	7.49	(0.77)		10.66	(7.14)	
Hydropower	0.57***	0.14***	0.48***	8.52***	2.38***	3.69**
	(0.07)	(0.02)	(0.06)	(0.72)	(0.49)	(1.68)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	21.21	-	-	21.21
Adjusted R-squared	0.28	0.97	-	0.29	0.83	-
N	2140	2140	2140	2140	2140	2140
	Percentage of workers in services			Percentage of workers in primary sector		
	OLS	FE	FE + IV	OLS	FE	FE + IV
	(7)	(8)	(9)	(10)	(11)	(12)
Mean (std. dev.)	4.58	(4.01)		36.16	(11.68)	
Hydropower	2.35***	0.67***	7.85***	-10.73***	-3.19***	-11.35***
	(0.41)	(0.22)	(0.80)	(0.99)	(0.55)	(1.54)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	21.21	-	-	21.21
Adjusted R-squared	0.31	0.85	-	0.35	0.88	-
N	2140	2140	2140	2140	2140	2140

Data: Norwegian censuses from 1891, 1900, 1910 and 1920.

Very small urban municipalities (below 8 km^2) are merged with their adjacent neighbors. Dependent variables: natural logarithm of the labor force size (inhabitants 15 years and older) in columns (1)-(3), percentage worker shares in manufacturing, services and primary sectors in columns (4)-(12). Data on sectoral affiliation is available for people aged 15 and older and present at the census count. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicator of coast and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table B.3: Hydropower effect on the level of sectoral employment

	Number of workers in manufacturing			Number of workers in services			Number of workers in primary sector		
	OLS	FE	FE + IV	OLS	FE	FE + IV	OLS	FE	FE + IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Mean (std. dev.)	195.29	(266.06)		78.06	(128.65)		673.34	(383.27)	
Hydropower plants	342.00***	142.15***	322.17***	114.96***	71.76***	235.93***	100.40**	5.85	-6.23
	(44.92)	(35.30)	(75.83)	(24.12)	(19.76)	(25.66)	(41.78)	(12.15)	(18.94)
Municipality FE	N	Y	Y	N	Y	Y	N	Y	Y
First stage F-statistics	-	-	21.46	-	-	21.46	-	-	21.46
Adjusted R-squared	0.25	0.74	-	0.24	0.56	-	0.27	0.96	-
N	1820	1820	1820	1820	1820	1820	1820	1820	1820

Data: Norwegian censuses from 1891, 1900, 1910 and 1920.

Dependent variables: workers in manufacturing, services and primary sectors in columns (1)-(3), respectively. Data on sectoral affiliation is only available for people aged 15 and older and present at the census count. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicator of coast and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table B.4: Hydropower adoption and the likelihood of upward mobility for manual workers belonging to different skill classes, OCSCORUS measure

	Lowest skilled (1)	Low skilled (2)	Medium skilled (3)	High skilled (4)
Panel A: sample of linked workers				
Hydropower production	0.07***	0.09***	0.19***	0.04***
	(0.02)	(0.02)	(0.04)	(0.01)
Adjusted R-squared	0.04	0.05	0.07	0.02
N	11473	41162	11090	13205
Panel B: sample of linked fathers and sons				
Hydropower production	0.14***	0.21***	0.19***	0.06***
	(0.05)	(0.03)	(0.05)	(0.02)
Adjusted R-squared	0.09	0.14	0.14	0.03
N	881	40103	2331	3956

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from the linked worker sample, while Panel B shows results from the linked father-son sample.

Dependent variables: indicators for upward mobility for manual workers belonging to five different skill classes. The skill classes are derived using the OCSCORUS measure. The measure ranks occupations using United States data on income from 1950. The classes are based on the following cutoffs: 9, 15, 20 and 25.

In the regressions we control for age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. All regressions include an indicator of coast, area of land, emigrant share in the decade preciding 1900 and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table B.5: Hydropower adoption and the likelihood of downward mobility for manual workers belonging to different skill classes

	Low-skilled		Medium-skilled		High-skilled		Highest-skilled	
	OCSCORUS	SEIUS	OCSCORUS	SEIUS	OCSCORUS	SEIUS	OCSCORUS	SEIUS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: sample of linked workers								
Hydropower production	0.01	0.00	-0.10***	-0.15***	-0.01	-0.12***	-0.06***	0.01
	(0.01)	(0.00)	(0.03)	(0.03)	(0.04)	(0.02)	(0.02)	(0.02)
Adjusted R-Square	0.02	0.02	0.07	0.07	0.04	0.07	0.07	0.05
N	46708	41162	11460	11090	1622	13205	9313	9502
Panel B: sample of linked fathers and sons								
Hydropower production	-0.11***	-0.09***	-0.08**	-0.14***	-0.10	-0.13***	-0.11***	-0.00
	(0.02)	(0.03)	(0.03)	(0.03)	(0.07)	(0.03)	(0.03)	(0.03)
Adjusted R-squared	0.18	0.11	0.09	0.10	0.04	0.07	0.03	0.05
N	40958	40103	3648	2331	463	3956	3360	3563

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from the linked worker sample, while panel B shows results from the linked father-son sample.

Dependent variables: indicators for downward mobility for manual workers in five different skill classes. The skill classes are derived using the OCSCORUS and SEIUS measures. The measures rank occupations using United States data on income and education from 1950. The former measure is based solely on income differentials, while the latter is based on income and education. The classes are based on the following cutoffs: 9, 15, 20 and 25.

In the regressions we control for age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. All regressions include an indicator of coast, area of land, share of emigrants in the decade preciding 1900 and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

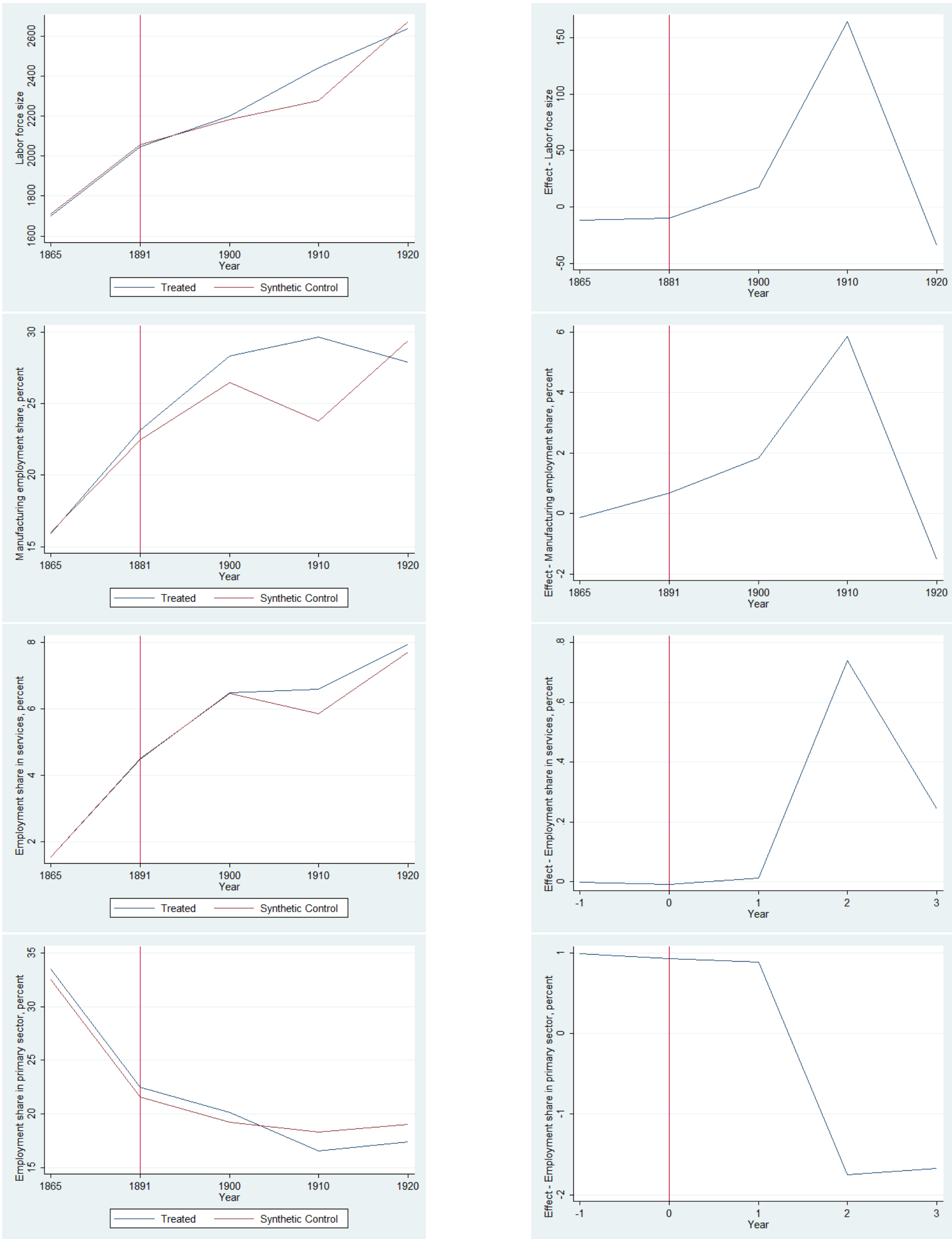
B.1 Robustness of aggregate results using synthetic control methods

To test the robustness of the results with a different estimation approach, we proceed with a synthetic control method with multiple treatment municipalities (Cavallo et al., 2013).[13] We focus on the municipalities that first adopted hydropower technology, just before 1900. Unfortunately, we have a rather limited time series for each municipality. We add data from the 1865 census to obtain a longer pretrend. This enables us to match on the level of the dependent variable in two periods, 1865 and 1891. We exclude municipalities that receive treatment in 1910 and 1920, and effectively match hydropower municipalities with municipalities that do not adopt hydropower technology in this period. The matching procedure is as follows. First, the program focuses on the pretrend of the treated municipalities. It matches the dependent variable by weighing selected non-treated municipalities to mimic the exact levels. The same weight matrix is used to create a counterfactual trend post treatment. The identification assumption is that matching on the level of the observables will also reflect the data-generating process that stems from the unobservables. In this case, because of the limited scope of the data, the method must be regarded as suggestive rather than conclusive.

The results are displayed in Figure 3. On the left hand side, we have the average trends for the 3 treated municipalities and their controls; to the right, we have the average effects. From the top two figures, which display the result for labor force size, we see that the effect seems to last for two periods before it abates. The same can said for the second and third row of graphs showing the results for employment shares in manufacturing and services, respectively. However, the effect is stronger in the first period for manufacturing and it also lingers in the third period for services. The primary sector result, in the last row of graphs, shows a small decline in this sector. However, the pretrend is poorly matched. Summing up, the results are quite similar to what we find with other estimation methods. Nonetheless, we are not fulfilling the data requirements for use of this method, and the results must be interpreted accordingly.

[13] We use the synth_runner package for Stata.

Figure 3: Effect of hydropower technology adoption on labor force size and structural transformation with synthetic control method



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