Who Benefited from Industrialization? The Local Effects of Hydropower Technology Adoption in Norway

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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 were often located in remote areas. We find that hydropower municipalities experienced faster structural transformation and displayed higher occupational mobility. We interpret this as evidence that this early twentieth-century technology was skill biased, as workers in the new skilled jobs were recruited from a broad segment of the population.

At the turn of the twentieth century, large parts of the world experienced widespread industrialization. The adoption of existing technologies as well as new technological breakthroughs profoundly altered the economic and social composition of local communities. On the one hand, these advances led to positive outcomes such as 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. For better or for worse, technological progress affected local labor markets and different types of workers in different ways and continues to do so today.

In a historical setting, these later waves of industrialization are often associated with positive outcomes brought about by skill demand (Goldin and Katz 1998; Katz and Margo 2014). Evidence of skill-biased technical

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change suggests that the gains from industrialization only benefited certain groups of workers, those that possessed the skills that were in demand. Another source of inequality in opportunity was related to location, as the level of development and sectoral specialization varied regionally and was related to the local supply of labor and other factor endowments (Kim and Margo 2004; Kim 2007). However, due to the gradual development of technologies, it is often not possible to go beyond description and identify relationships between technological improvements and relevant economic outcomes. For that reason, we make use of a quasi-natural experiment to identify the impact on local economic conditions and occupational outcomes for workers with different skills and backgrounds.

We provide evidence of the heterogeneous impact of rapid technological development by exploiting the expansion of hydropower technology in Norway from 1890 onward. Electrification and dam construction have been used to study historical data in other applications (see, for instance, Severnini 2014; Kitchens and Fishback 2015; Lewis 2018). Several features of the hydropower expansion in Norway suggest that it is independent of other economic activity. First, hydropower production depends on specific geographical properties—the terrain must be suitable (with a sufficient slope) and there must be enough water flow. Many of the facilities were located in remote areas with mostly agrarian production. Second, the transmission technology was still in its infancy. Hence, electrical power had to be used close to where it was produced (Vogt 1971; Hughes 1993).[1] These conditions point to a strategy of comparing outcomes across municipalities with different natural attributes. To test the validity of the approach, we apply several estimation strategies to deal with confounders. We use a geographical instrument to predict the location of hydropower production, which displays no significant relationship with municipality pre-trends. We also apply fixed effects (FE) methods and sample restrictions.

There are several reasons why Norway is a suitable context for studying changes to the local economic conditions using electrification as a quasi-independent driver of industrialization. In 1890, at the beginning of the period we study, the Norwegian economy had undergone only a limited industrial revolution (Venneslan 2009). Over the next 30 years, more than 140 hydroelectric power plants would be constructed, mostly in rural areas. The technology was imported from abroad and partly

[1] The first transmission line to the capital city of Kristiania (Oslo) from another region, Rjukan, was established in 1922, after the period we study. The first major connection of power networks took place in 1928, with the hydropower plant at Nore transmitting 200 MW on a 132-kV line to the Oslo area (Vogt 1971; Statnett 2018).

financed with foreign capital. The historical circumstances make it less likely that the results are affected by unobserved characteristics and more likely that investors established power plants based on the geography of Norway. In addition, access to rich population-wide census data makes it possible for us to go further than many other studies.

To investigate the local effects of hydropower technology adoption, we proceed in two steps. First, using municipal data, we investigate how labor force size and sectoral employment shares were affected by hydropower technology. These analyses are informative in themselves and are also used to motivate and interpret subsequent analyses. Second, we examine how general and intergenerational occupation mobility varied across hydropower and non-hydropower municipalities. For this purpose, we use linked census microdata and distinguish between workers belonging to different occupational groups. We find that municipalities that adopted the new technology show signs of faster structural transformation, as hydropower municipalities display a relative expansion in employment in manufacturing 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 were more likely to obtain higher-skilled positions in hydropower municipalities, and the intergenerational mobility of sons of unskilled workers was relatively high in these municipalities.

RELATED LITERATURE

This paper draws on several strands of literature in historical economics, the first of which provides evidence of the importance of energy technology and energy resources and tends to emphasize regional changes in sectoral composition, specialization, and productivity, as well as changes in employment and population. The second chronicles the opportunity to advance in society during periods of industrialization and technological change. We follow both avenues of investigation using plausibly exogenous variation in the implementation of new energy technology, which yields a more comprehensive understanding of the societal and economic processes taking place.

The importance of energy technology and location of energy resources for industrialization is at the core of this paper. One prominent tradition within economic history places coal at the center of the industrialization process, as it fueled the groundbreaking steam-engine and the smelting industries. In a historical setting, proximity to coal deposits and production has been studied in relation to population growth and manufacturing activity (Crafts and Mulatu 2006; Fernihough and O'Rourke 2014); however, there is evidence of the association turning negative in the longer run (Matheis 2016; Clay and Portnykh 2018).[2]

In contrast, the literature on the impact of dams on economic development tends to find positive effects both in the short and longer term. For instance, 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 agricultural employment in the short run and manufacturing employment growth in the long run from such investments. Similarly, Severnini (2014) finds short- and long-run growth effects on employment and population from dam construction in the United States in the first half of the twentieth century. Other contributions in the field focus on the availability of electricity and the process of electrification.[3] Kitchens and Fishback (2015) find positive effects on rural development and agricultural productivity due to extensions of the electricity grid in the United States in the 1930s. Studying the electrification of rural areas in the United States during 1930–1960, Lewis and Severnini (2017) find increases in agricultural employment, population, and property values and Lewis (2018) finds a decrease in infant mortality. Using U.S. census data from 1920 to 1940, Gaggl, Gray, and Morin (2015) show that electricity expansion leaves the population size unchanged and leads to re-allocation of workers from farms to factories with upward movement in the earnings distribution for transitioning workers.[4]

We contribute by investigating changes to population and sector employment following hydropower adoption, at a detailed geographical level with full-count census data and a stringent estimation strategy. In our strictest specifications, we both impose local FE and employ an instrumental variable (IV) approach to deal with endogenous placement of plants and unobserved municipality growth paths. This yields some novel results. Also, in contrast to many of the papers in this field, the variation we are exploiting originated from a technological breakthrough

[2] Compared to the historical literature on dams and electrification, the literature on coal has focused more strongly on the detrimental effects in the longer run, the so-called resource curse. A description of the mechanisms causing detrimental outcomes can be found in Michaels (2010) and Matheis (2016).

[3] There are also contributions that study the effects of changes in electricity prices (see, for instance, Morin 2015).

[4] There is also literature that surveys experience of electrification and dam constructions in developing countries that may resemble the past experience of industrialized countries (e.g., Duflo and Pande 2007; Dinkelman 2011; Lipscomb, Mobarak, and Barham 2013).

interacted with local natural characteristics instead of changes being spurred by policy.

When it comes to changes in living conditions during industrialization, a key point of disagreement in the literature is when and how living standards improved following growth in the aggregate economy.[5] A seminal paper by Goldin and Katz (1998) shows that the gains from technological advancements in the early twentieth century were not equally distributed among all types of workers. They provide a framework for understanding technology-skill complementarity. Using data on U.S. industries between 1909 and 1940, they find that industries that used more capital employed higher-educated workers and paid higher education premia. This contrasts with research on earlier periods, in particular, nineteenth-century Great Britain, where high-skilled workers and capital appear to have been substitutes (Acemoglu 2002). 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 using low-skilled labor. Later, increases in the supply of skilled workers led to development of skill-complementary technologies.

Recent studies, using U.S. data from the nineteenth and twentieth centuries, show a more complex relationship between skills and new technology. Studies show that there has been a polarization of job distributions ("hollowing out"): a decrease in jobs with intermediate returns and an increase in high- and low-return jobs (Gray 2013; Katz and Margo 2014). Due to limitations in historical data, these changes are typically studied in the aggregate, as it is not possible to follow individuals over time.[6] This hollowing out pattern is also found in contemporary data (see, for instance, Autor, Katz, and Kearney 2006; Goos, Manning, and Salomons 2009, 2014), which may suggest that this has become a persistent trait of technological change.

[5] Much of this literature relates to the Industrial Revolution in Great Britain in the eighteenth century, for example when and how living standards improved following real wage growth in the aggregate economy and whether there was a fall in living standards in the early phases of industrialization (see, for instance, Clark 2005; Allen 2009). There is disagreement as to whether wages can provide a good measure of the standard of living (Broadberry et al. 2015, chap. 6); an alternative perspective is to look at physical outcome measures such as stature. For Norway, the canonical series of wage development is given by Grytten (2007). Real wage growth is stagnant from around 1850 to 1870, followed by a 30-year period of rapid growth. After 1900, the growth rates are positive. The hydropower expansion, therefore, overlaps with a period of growth in Norway.

[6] For more recent periods, this is sometimes feasible. For example, Cortes (2016) tracks the occupation paths of workers in disappearing routine occupations in the late twentieth-century United States.

What evidence there is on changes in individual economic trajectories (as opposed to general growth) in the period we study is generally limited to occupational outcomes. The aim of this paper is to expand on the national evidence and study regional differences in mobility. This study's contributions to the literature are made possible by two favorable properties of the dataset. First, it stands apart by investigating occupational mobility using full-count individual data for the early twentieth century, as such data are typically not available for this period. Second, the geographical detail allows for relatively high match rates over time for workers and father-son dyads and investigation of localized effects.

The extent of occupational mobility in Europe during industrialization is generally thought to have been limited. Long and Ferrie (2013) document that while intergenerational occupational 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). To our knowledge, no previous studies have examined how intergenerational mobility is affected by place-specific technology and industrialization shocks.[7] For the same reason, little is known about changes in individual occupational trajectories (intragenerational mobility) in response to industrial development in this period. In this paper, we also contribute to the scarcer evidence of the consequences of industrialization outside of the core industrializing countries.

BACKGROUND, DATA, AND EMPIRICAL STRATEGIES

Hydroelectricity and Industrialization in Norway

Norway was a relatively late industrializer compared to the rest of Western Europe. By the end of the nineteenth century, 11.9 percent of the population was employed in manufacturing, compared to 8 percent 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 non-agricultural employment options in rural areas, including fisheries and employment at sea.

[7] Regional studies of mobility and economic conditions are available for more recent periods, such as Feigenbaum (2015) (Depression-era United States) and Bütikofer, Dalla-Zuanna, and Salvanes (2018) (late-twentieth-century oil boom in Norway).

Waterfalls had been used for economic production for a long time; sawmills powered by water ("oppgangssager") were established in the early sixteenth century (Helle et al. 2006, p. 160), and river flour mills were in use even earlier (Tvedt 2000). The conversion of water potential into electrical energy greatly expanded its possible applications. 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 (Bjørsvik, Nynäs, and Faugli 2013). Initially, the small power plants were mainly used for lighting in manufacturing plants, privately owned houses, and streets. This changed dramatically over time. Venneslan (2009) documents that total energy consumption in manufacturing from electricity-driven operations rose from 1.2 percent and 5.8 percent in 1896 and 1905 to 44.6 percent and 79.8 percent in 1910 and 1920, respectively.

The establishment of the electro-chemical industry was one of the forces that pushed the Norwegian economy into more extensive industrialization. It started at the turn of the century with the production of carbide.[8] 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). Using a new electro-chemical technique to produce potassium nitrate developed by Birkeland and Eyde, in 1905, the company Norsk Hydro built the Svælgfos power plant, the largest of its kind in Europe (Jensen and Johansen 1994). The invention had global economic significance, as it was critical for assuring agricultural production. Exports of saltpeter from Norway 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 refined iron, zinc, nickel, steel, 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

[8] This was initiated first at Sarpsborg in 1899 (Hafslund and Borregaard), next at Meråker in 1900 (Meraker Bruk) and finally at Notodden in 1901 (Notodden Calcium Carbidfabrikk).

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 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).

The new technology dramatically enhanced the value of previously non-exploitable waterfall resources (Bergh et al. 1981). Norway lacked the technological competencies and financial institutions to handle the endeavors, so a substantial part of the financing came from abroad. There was a current account deficit of between 16 and 33 percent of gross investment in the period 1895–1914, and 39 percent of listed manufacturing firms were foreign owned in 1909 (Hodne and Grytten 2002, p. 44). In 1909, 85 percent of the capital in chemicals, 47 percent in electricity production, and 44 percent in paper and pulp production was foreign owned (Bergh et al. 1981).

The interest of foreign investors points to the geography of Norway being crucial to the establishment of hydropower plants. Foreign owners' main interest is profit, whereas governments are more likely to also be concerned about the general supply of electricity and local investors may, to some extent, be steered by attachment to places and patriotism. Foreign investors are likely to compare the Norwegian waterfalls with waterfalls in other nations when deciding where to invest. Other evidence suggesting that foreign investors bought the best of the Norwegian waterfalls comes from the legal realm. Around 1905, there were public reactions against foreign penetration in the economy and the loss of the best waterfalls to foreign interests. 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).

Population Data, Municipal Structure, and Hydroelectric Production

In our data, the locations of hydropower plants and individuals are recorded at the municipal level. At the time, Norwegian municipalities were small units originally based on church parishes. Local government 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 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.[9] Summary statistics of selected variables from the aggregate analysis are shown in Table 1, which also displays how the means changed over time. From 1891 to 1920, the average labor force size and the employment shares in manufacturing and service sectors grew, while the primary sector share decreased.

To minimize the role of confounding factors, we focus on rural areas.[10] We omit cities and municipalities adjacent to them from the sample and end up with 455 municipalities.[11] The average population of the rural municipalities in 1900 was 2,775 (std. dev. = 1,741) and the average size was 654 km^2. For 1900 and 1910, we have access to full-count records of all individuals resident in Norway; we return to these data below. Descriptive statistics of all the variables used in the municipal and individual datasets can be found in Online Appendix A.

There was substantial out-migration from Norway to the United States in the period we study. The validity of our results is limited to those who are present in Norway in the census years that we consider. We note that in their study of Norwegian–U.S. migrant selectivity, Abramitzky, Boustan, and Eriksson (2012) find no evidence of any systematic selection of migrants from rural areas in Norway to the United States.[12] For this reason, we do not expect international migration to impose any substantial bias on our results. We do, however, control for emigration (aggregate emigration numbers are available at the municipality level

[9] For aggregate municipal data, we use digitized data made available by the Norwegian Center for Research Data (NSD). (NSD is not responsible for the analysis or interpretation of results based on the data they collect.) The aggregate analysis is based on the population aged over 15 years. Further information on the data and the generation of the variables can be found in Online Appendix A, and robustness tests of variable definitions, sample years, and estimation strategy can be found in Online Appendix D. A replication package, including municipal-level data and all do-files, is available at OpenICPSR (Leknes and Modalsli, 2019).

[10] Results for all municipalities, urban ones included, can be found in Online Appendix D. The results are similar to the baseline.

[11] 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.

[12] Abramitzky, Boustan, and Eriksson (2012) do find evidence of negative selection from urban areas.

TABLE 1
SUMMARY STATISTICS FOR MUNICIPALITY LEVEL ANALYSES

	All Periods		Year 1891		Year 1920	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Labor force size (pop. aged 15+)	1828.60	(1222.09)	1696.61	(993.66)	2049.74	(1531.46)
Employment share in manufacturing	9.20	(5.99)	8.05	(4.54)	10.02	(6.51)
Employment share in services	2.62	(2.07)	1.62	(1.22)	3.64	(2.60)
Employment share in primary sector	39.10	(8.72)	42.46	(8.00)	38.39	(9.84)
Number of hydropower plants	0.07	(0.32)	0.00	(0.00)	0.21	(0.56)

Source: Information on population size and industry employment shares are from the Norwegian census 1891–1920. Further details are in the text and in Online Appendix A.3. Information on hydropower plants are collected from the Norwegian Water Resources and Energy Directorate (1946) and other sources, see Online Appendix A.1.

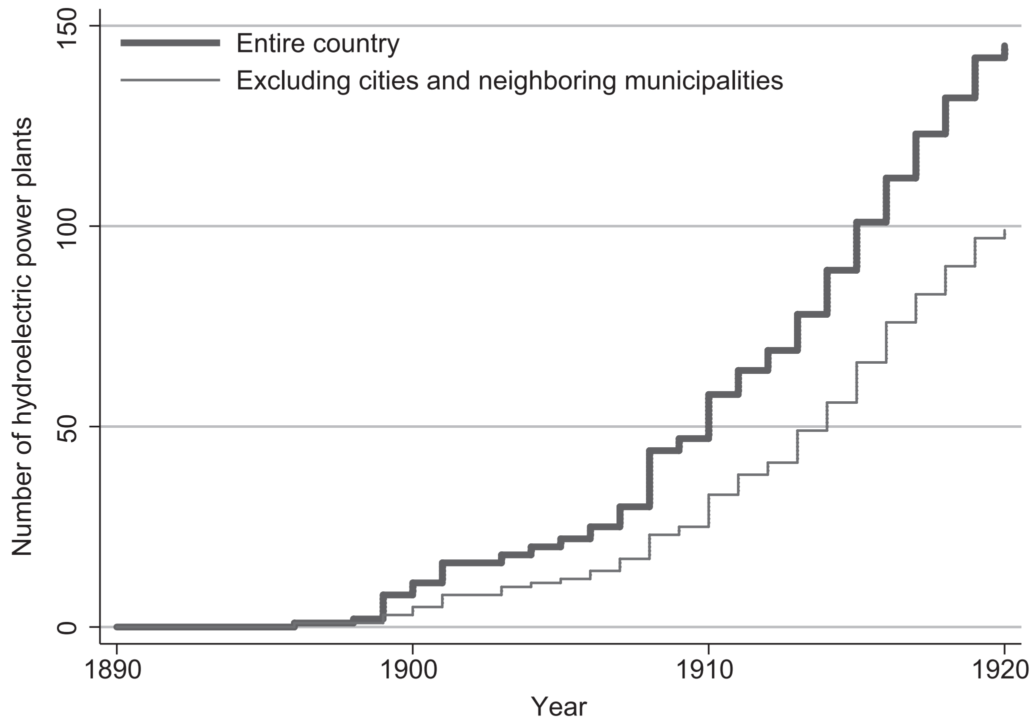

FIGURE 1
NUMBER OF HYDROPOWER PLANTS, BY YEAR

Source: Norwegian Water Resources and Energy Directorate (1946) and other sources. Further details are in the text and in Online Appendix A.1.

as annual or sometimes 5-year aggregates) in our baseline econometric specifications, as detailed below.

The data on hydropower plants are taken from detailed tabulations published by the Norwegian Water Resources and Energy Directorate (1946). The publication provides information on start year and generator capacity. We omit very small plants with generator capacities of less than 500 kW, as they are not expected to have an effect on the local labor market.[13]

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 97 plants in 74 municipalities in 1920. The geographical distribution and start period can be seen in Figure 2. By 1920, the plants are distributed across the entire country.

[13] 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 Online Appendix A.1.

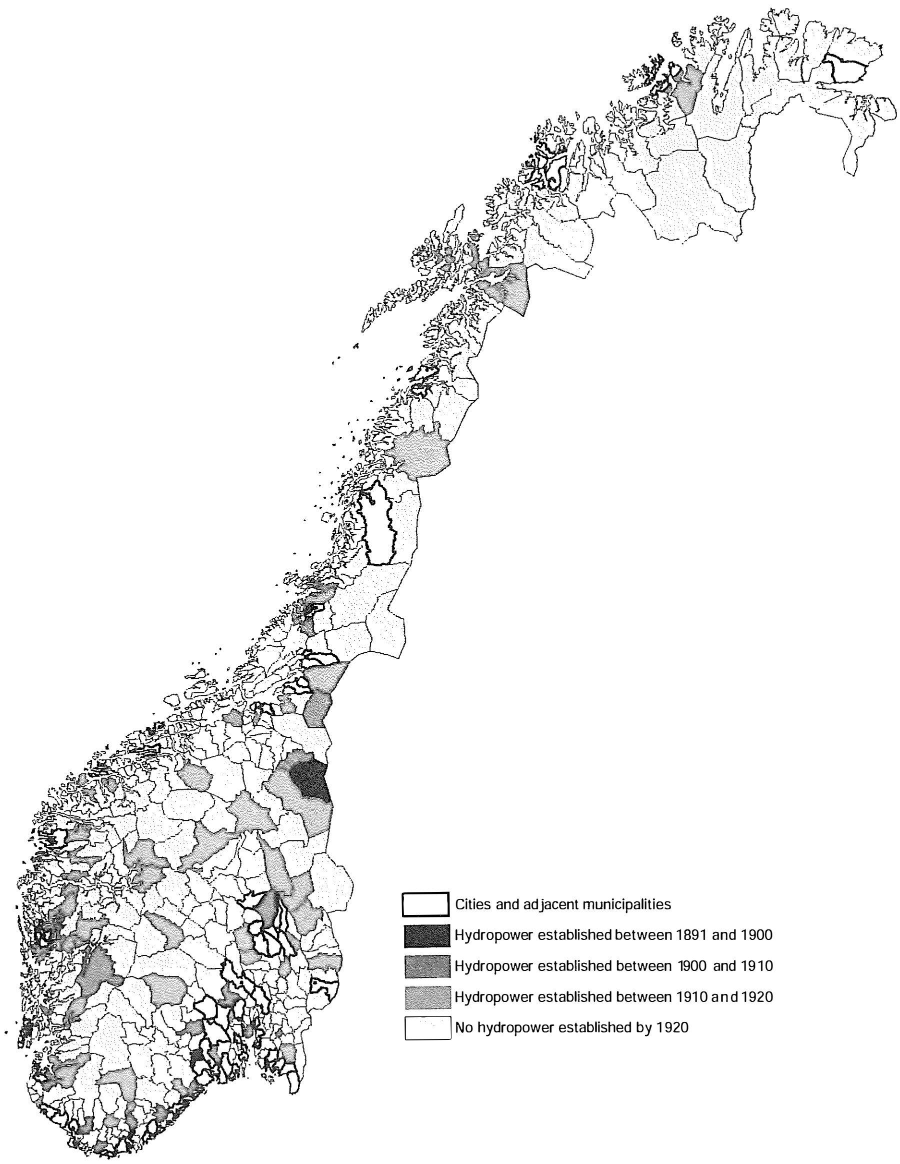

FIGURE 2
ILLUSTRATION OF HYDROPOWER TECHNOLOGY ADOPTION IN NORWAY, 1891–1920

Source: Norwegian Water Resources and Energy Directorate (1946) and other sources. Further details are in the text and in Online Appendix A.1.

Linked Micro Data

All individual records in the censuses of 1900 and 1910 have been transcribed and made available through a collaboration between the Norwegian National Archives, the Norwegian Historical Data Centre, and the IPUMS (Minnesota Population Center 2017; The Digital Archive

2008, 2011). The records contain information on names, ages, places of residence, and occupations (coded in the HISCO standard) of all individuals resident in Norway in those two years. Of special interest is the occupation information, as it provides valuable information about individuals' status and their place in the economy. When a parallel is drawn between occupations and standards of living, there is an underlying assumption that high-skilled occupations are better paid than unskilled occupations. Crude tabulations of incomes across the broad occupations, identical to those used in the present paper, support this assertion for Norway in the early twentieth century.[14]

We linked the individual records using an algorithm that evaluates similarities in name, year of birth, and place of birth for all pairs of records in 1900 and 1910. The algorithm is presented in detail in Modalsli (2017); a summary is given in the Online Appendix Section B. The use of linked micro data in studies of economic history has recently been increasing, though most studies have been of census data from the United States (Bailey et al. 2018). The methodology used here takes advantage of some special characteristics of the Norwegian data, notably that complete-count samples are available for both years and that birthplace is reported at a very detailed level (municipality).[15] It also handles the challenge that Norwegian surnames were not completely standardized in this period, so that fathers' names and place names of origin are also taken into account. As is now common in the literature, we allow for dissimilarities in the spelling of names, as well as inaccuracies in the reporting of birth years and birth locations. In principle, a composite score for any combination of records from 1900 and 1910 is created, based on similarity in each of the four variables (first name, surname, birth year, and birth municipality). A match is accepted if it is sufficiently good (i.e., if the characteristics are similar) and at the same time unique (for instance, there are no other good candidates in either year for each of the observations). In this way, 44 percent of all men above the age of 25 in 1910 can be linked to a household in 1900.

From the linked data, we obtain information on an individual's occupational mobility (change in occupation over these ten years) for older

[14] A 1915 tabulation of incomes across census occupations indicates that incomes for men in manual skilled occupations in 1910 were 80 percent higher on average than those of men in manual unskilled occupations. Men in white-collar occupations had incomes more than three times higher. For details, see Online Appendix A.7.

[15] While 100 percent of the samples of U.S. census data are now available for most censuses from this period, this was not the case until recently and much early work on record linkage was done on smaller samples.

individuals and intergenerational mobility (comparison between the individual's occupation and that of his father) for younger individuals. The link between father and son is obtained by observing them in the same household in 1900. The same individual linkage process for the censuses of 1865 and 1900 is used in supplementary analyses.

While the link rate in this study is substantially higher than those in other historical studies (e.g., Abramitzky, Boustan, and Eriksson 2012; Long and Ferrie 2013), some selectivity concerns remain. As there was substantial international migration in the period under study, mainly from Norway to North America but also some return migration to Norway, knowing the "true" match shares (what one would get with 100 percent match rates) is not possible.[16]

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 their earnings potential is possibly more related to the nature of the farm (which is unobservable in our data) than to human capital. For this reason, we do not consider farmers in our baseline measure of mobility.

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.[17] 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.

Estimation Strategies

First, we discuss how to examine changes in aggregate employment as a result of hydropower technology adoption, before turning to the investigation of occupational changes of individual workers. Let y_{mt} denote

[16] Balancing tests presented in Modalsli (2017) point toward a moderate oversampling of farmers. This may be a consequence of individuals from smaller (rural) municipalities being easier to match; those from larger municipalities will more frequently have other match candidates (individuals with the same name born in the same year) and, hence, not be accepted by the matching algorithm.

[17] Examples of the classification are given in Online Appendix Table A.4. We return to a further disaggregation of manual occupations in the penultimate section of this paper.

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. Hydropower production is only feasible in places where certain natural features are present. If these natural features are independent of our outcome variables, hydropower production status provides as-good-as-random variation and we can estimate the average treatment effect, β_1, by ordinary least squares (OLS):

$$y_{mt} = \beta_0^1 + \beta_t^1 + \beta_m^1 + \beta_1^1 HP_{mt} + \mathbf{X}_{mt}\boldsymbol{\delta}^1 + \varepsilon_{mt}^1 \tag{1}$$

However, if there were places that were perceived as more or less suitable owing to natural and other municipality characteristics, for instance, factors that affect general productivity, housing supply elasticities, and our employment variables, this would obstruct this estimation strategy. To deal with heterogeneity at the municipal level, we first control for observable characteristics of the municipalities ($\mathbf{X}_{mt}$). This vector of municipality characteristics includes area size (km^2) an indicator of coast and emigration share.[18] As infrastructure has been related to sectoral skill demand (Michaels 2008), infrastructure items that pre-date 1891 are also included in the vector: coach stops, railway stations, and ship and steamboat routes. Second, we include FE for each municipality (β_m). The variable of interest is then identified from the within variation of municipalities, at the cost of making the results more prone to attenuation bias due to measurement error. For this reason, we report additional results where the municipality FE are replaced with 18 county FE. β_t represents census FE and ε is an error term assumed to have the usual properties.

If plant locations are, to some extent, ruled by strategic decisions rooted in unobserved characteristics that also affect the municipality growth paths, the estimated relationships might be biased. For instance, the hydropower industry and other industries are likely to locate where the most appropriate supply of labor can be found. To deal with endogenous placement and confounders, we instrument hydropower production status with a measure of hydropower potential.[19] The measure is based on the geographical properties of rivers, and detailed descriptions and tests of instrument relevance and excludability can be found in the next section. The identification assumption is that conditional on observed

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

[19] The arguments for instrumentation are analogous to those in Dinkelman (2011).

municipality characteristics, municipality, and census FE, hydropower potential does not affect employment in the municipality except through the likelihood of hydropower plants being established.

We allow hydropower potential z_m to have a different impact in each decade by interacting the measure with census FE. We expect the establishment of hydropower plants to follow a rational schedule, where the most suitable locations are developed first and marginally less suitable locations follow in subsequent steps. The first-stage results, reported later in the paper, show that this expectation is warranted with hydropower potential having an increasing impact over time. The first-stage equation is specified in the following way:

$$HP_{mt} = \beta_m^2 + \beta_t^2 + \alpha_1 z_m \mathbf{1}(1900) + \alpha_2 z_m \mathbf{1}(1910) + \alpha_3 z_m \mathbf{1}(1920) + \mathbf{X}_{mt}\boldsymbol{\delta}^2 + \varepsilon_{mt}^2 \quad (2)$$

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 an individual's own or his father's occupation in 1900, we are left with a cross section of occupational histories at the individual or "dynasty" (family) level. We omit workers who are resident in a hydropower municipality in 1900 and estimate the following specification:

$$y_{im} = \beta_0^3 + \beta_c^3 + \beta_1^3 HP_m + \mathbf{X}_{mt,1900}\boldsymbol{\delta}^3 + \mathbf{X}_{i,1900}\boldsymbol{\gamma}^3 + \varepsilon_{im}^3 \quad (3)$$

Let y_{im} be an indicator for change in occupation consistent with upward mobility for individual i. We focus on manual unskilled workers/fathers in 1900, who will have experienced upward mobility if they/their sons belong to a manual skilled or white-collar occupation in 1910.[20] In the baseline specification, HP_m is an indicator of obtaining hydropower production between 1900 and 1910 in the 1900 municipality of residence.

It is not feasible to include municipality FE in the cross-sectional dataset. However, we can mitigate the influence of more aggregated area characteristics by adding county FE β_c. In addition, we include the observed municipality characteristics ($\mathbf{X}_{m,1900}$) of the 1900 municipality of

[20] Because of the ambiguous status of farmers, we do not consider transitions from unskilled worker to farmer as occupation upgrading (see the discussion on linked micro data above). We also investigate upward mobility for farmers and skilled workers in Online Appendix D. The results for these groups are not significant.

residence. Worker/son characteristics may be correlated with the opportunity to experience occupational advancement, and these traits might differ across municipalities with and without hydropower plants. We, therefore, include a vector of 1900 worker/son characteristics ($\mathbf{X}_{i,1900}$) that include age, age squared, indicator of being married, number of children, and an indicator of not being resident in municipality of birth. We also instrument hydropower production by hydropower potential to deal with the issues of endogenous placement of hydropower plants and unobserved confounders. The exclusion restriction is now that conditional on observed municipality characteristics, county FE, and individual characteristics, hydropower potential does not affect upward occupational mobility except through the increased probability of hydropower plants being established.

Hydroelectric Potential as an Instrument

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

$$HydroPotential_m = z_m = \frac{\sum_{v=10}^{v=750} (River4_{vm} \times v)}{Area_m} \tag{4}$$

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 rivers in Norway into water volume classes, v.[21] 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. Like Borge, Parmer, and Torvik (2015), we focus on river stretches with a gradient of 4 degrees or more. $River4_{vm}$ is meters of river with water volume class in terrain with a slope of 4 or more in municipality m. Next, for each river class, we multiply meters of river by maximum water flow in that class. Finally, we take the sum of these products and divide by the total area (km^2).[22]

Norwegian municipalities vary widely in geographical size. We adjust the measure of hydropotential by the size of the municipality to obtain a

[21] 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, and 600-750.

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

scale-independent measure that 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 allowing the influence of hydropower potential to differ between census years, municipality fixed-effect estimations are feasible. This specification fits better with the expected data generation process. There is strong persistence in the location of hydropower plants, and we expect the effect of the instrument to increase and be more sharply estimated as more of the suitable locations are developed. Table 2 displays the first-stage results from the municipality and individual regressions. As can be seen, all coefficients are positive, supporting the theory that higher hydropower potential increases the probability of obtaining hydropower technology. Using the linked worker results in Column (3), increasing hydropower potential by 0.55 (e.g., one standard deviation) leads to $0.104 \cdot 0.55 = 0.057$ percentage points higher probability of residing in a hydropower municipality in 1910.[23] The impact of the instrument increases over time as the most suitable waterfalls are exploited. The first period instrument, with only a few established hydropower plants, does not provide a significant result conditional on the other instruments. However, the joint significance, demonstrated by the first-stage F-value, is high. It is also worth mentioning that the instrument coefficients are similar across the regressions carried out using the municipal panel dataset and the linked datasets.

Is hydropotential a valid instrument? The exclusion condition is that, conditional on covariates, hydropower potential affects labor force size, structural transformation, and upward occupational mobility only through its effect on the likelihood of a municipality obtaining hydropower plants. In other words, hydropower potential should not be correlated with unobserved factors in the structural equation and, thereby, the error term. This condition cannot be checked directly, as it involves a relationship between the error term and the instrument(s). We argue that this restriction is likely to hold; the mechanical river power technology was small-scale compared to hydroelectric technology where rivers of greater size and steepness could be exploited. To test the excludability argument, we conduct an indirect test. We use the instrument to estimate changes in outcomes in the period 1890–1900, a period when few municipalities had established hydropower technology. We exclude municipalities with

[23] One standard deviation change in hydropower potential corresponds to an increase in probability of 0.06 percentage points.

TABLE 2
FIRST-STAGE RESULTS, HYDROPOWER PRODUCTION AND POTENTIAL

	Municipality Sample		Linked Samples	
			Linked Workers	Linked Fathers-Sons
	(1)	(2)	(3)	(4)
Hydropower potential 1900	0.028	0.028	—	—
	(0.025)	(0.027)		
Hydropower potential 1910	0.094***	0.095***	0.104***	0.104***
	(0.023)	(0.025)	(0.025)	(0.030)
Hydropower potential 1920	0.126***	0.127***	—	—
	(0.026)	(0.029)		
County FE	Yes	No	Yes	Yes
Region FE	No	Yes	No	No
Adjusted R^2	0.15	0.28	0.15	0.15
N	1,820	1,820	30,824	10,542
First-stage *F*-value	10.23	10.84	17.05	12.21

Notes: Data from Norwegian censuses of 1891, 1900, 1910, and 1920. Columns (1) and (2) display first-stage results for the municipality regressions, while Columns (3) and (4) display the results from the linked samples. Dependent variable: indicator of hydropower production in the municipality (of residence). Variable of interest: hydropower potential per thousand (interacted with census year). All specifications control for geographical size of municipality (km^2), indicators of coast, historical infrastructure variables, and lagged emigration share. In Columns (1) and (2), the regressions also control for year FE. In Columns (3) and (4), the regressions include 1,900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and indicator of not being a resident in municipality of birth. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

hydropower in 1900 and those that were constructing plants at that time. As shown in Table 3, the instrument (per thousand) has no significant effect on labor force size or workers in different sectors. These results strengthen the claim that the exclusion restriction holds.

HYDROELECTRICITY AND STRUCTURAL TRANSFORMATION

The new technology made it possible to produce electrical power from waterfalls; consequently, some areas gained production advantages. 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 are determined by both demand and supply factors. If the

TABLE 3
ESTIMATIONS OF RELATIONSHIP BETWEEN INSTRUMENT AND LABOR FORCE SIZE AND SECTOR SIZE IN THE PRE-PERIOD, 1891–1900

		Percentage of Workers		
	Ln(Labor Force Size)	Manufacturing	Services	Primary Sector
	(1)	(2)	(3)	(4)
Hydropower potential	–30.41	0.58	0.01	–0.38
per thousand	(28.66)	(0.41)	(0.12)	(0.51)
Adjusted R^2	0.46	0.21	0.16	0.14
N	449	449	449	449

Notes: Data from Norwegian censuses from 1891 and 1900. Dependent variables: natural logarithm of the labor force size (inhabitants 15 years and older) and percentage worker shares in manufacturing, services, and primary sectors. Data on sectoral affiliation are available for persons aged 15 and older and who were present at the census count. Regressions control for county FE, geographical size of municipality (km^2), indicators of coast, lagged emigration share, and infrastructure variables. The regression omits municipalities that had established hydropower plants or were constructing such in 1900 or earlier.
Robust standard errors are in parentheses. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

local demand for workers exceeds the local supply, we might observe an influx of workers. 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 processes, we expect the treated municipalities to shift from primary sector production to manufacturing production. We might also observe shifts toward the service sector if the adoption of hydropower technology caused increased local economic activity of a certain magnitude.

The estimated relationships between hydropower status, labor force size, and sectoral employment shares are displayed in Table 4. For each outcome, we estimate the relationship on the basis of the three specifications described above: OLS, municipality FE, and FE with IV estimation.

First, we observe that according to the FE and OLS models, municipalities where hydropower technology was implemented experience labor force expansion. These models show effect sizes of 39 and 14 percent, respectively. The effect size in the FE model is only one-third that in the OLS model, suggesting potential selection effects: The OLS result also captures underlying differences between municipalities with different natural endowments, while the FE model corrects for such differences provided they are time-invariant. The IV + FE estimate in Column (3) is non-significant and has a point estimate close to zero. If we look at the

TABLE 4
HYDROPOWER PRODUCTION, LABOR FORCE SIZE AND INDUSTRY COMPOSITION

	Ln(Labor Force Size)			Percentage of Workers in Manufacturing		
	OLS (1)	FE (2)	FE + IV (3)	OLS (4)	FE (5)	FE + IV (6)
Hydropower	0.39***	0.14***	–0.04	8.04***	2.66***	4.35
	(0.07)	(0.03)	(0.19)	(1.16)	(0.79)	(2.96)
Municipality FE	No	Yes	Yes	No	Yes	Yes
First-stage *F*-statistic	—	—	10.84	—	—	10.84
Adjusted R^2	0.33	0.97	—	0.32	0.74	—
N	1,820	1,820	1,820	1,820	1,820	1,820
	Percentage of Workers in Services			Percentage of Workers in Primary Sector		
	OLS (7)	FE (8)	FE + IV (9)	OLS (10)	FE (11)	FE + IV (12)
Hydropower	1.04***	0.45	–2.78*	–9.41***	–4.07***	–3.98
	(0.26)	(0.27)	(1.63)	(1.22)	(0.86)	(3.19)
Municipality FE	No	Yes	Yes	No	Yes	Yes
First-stage *F*-statistic	—	—	10.84	—	—	10.84
Adj. R^2	0.37	0.67	—	0.41	0.77	—
N	1,820	1,820	1,820	1,820	1,820	1,820

Notes: Data from 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) and percentage worker shares in manufacturing, services, and primary sectors in Columns (4)–(12). Data on sectoral affiliation are available for persons aged 15 and older. Regressions control for year FE, county FE, geographical size of municipality (km^2), indicators of coast, infrastructure, and lagged emigration share. Instruments are hydropower potential interacted with decade indicators. Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV estimates follows Arellano (1987). Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

reduced form in Column (1) of Table 5, the estimate is also insignificant. Accordingly, places that obtained hydropower experienced population growth in typically working ages, but this effect might be driven by the unobservables that characterize the potential endogenous placement of plants. The result is in line with the study of Gaggl, Gray, and Morin (2015), which finds no population effects from electrification.

Second, municipalities that obtain hydropower production display a substantial increase in the manufacturing employment share with the OLS and FE models (Columns (4) and (5)). Again, moving from an OLS

TABLE 5
REDUCED FORM RESULTS. RELATIONSHIP BETWEEN NATURAL HYDROPOWER POTENTIAL, LABOR FORCE SIZE, AND SECTOR EMPLOYMENT SHARES

		Percentage of Workers in		
	Ln(Labor Force)	Manufacturing	Services	Primary Sector
	(1)	(2)	(3)	(4)
Hydropower potential 1900	0.013	1.732***	–0.156	–0.954**
	(0.019)	(0.652)	(0.097)	(0.370)
Hydropower potential 1910	–0.002	0.964**	–0.282*	–0.326
	(0.019)	(0.377)	(0.154)	(0.405)
Hydropower potential 1920	0.001	1.133**	-0.385	–0.981*
	(0.034)	(0.441)	(0.235)	(0.560)
Adjusted R^2	0.96	0.74	0.67	0.76
N	1,820	1,820	1,820	1,820

Notes: Data from Norwegian censuses of 1891, 1900, 1910, and 1920. Dependent variables: potential labor force size and sector employment sizes. The instruments are scaled per thousand. Estimator: OLS. All specifications control for geographical size of municipality (km^2), indicators of coast, historical infrastructure variables, lagged emigration share, and municipality and census FE. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

to a FE specification reduces the coefficient estimate; the estimate falls from 8 to 2.7 percentage points, respectively. The IV + FE estimate in Column (6) is positive and indicates that the manufacturing employment share expands by 4.35 percentage points following the establishment of hydroelectric power. The estimate is, however, not statistically significant at conventional levels (*p*-value of 0.14). There is also other evidence supporting the reliability of hydropower-induced changes to manufacturing employment: We find positive and significant effects with the FE + IV specification for alternative definitions of manufacturing employment. Online Appendix Table D.4 shows that hydropower production increases manufacturing employment (number of workers), with 0.79 of a standard deviation, and in Online Appendix Table D.5, where manufacturing is more narrowly defined to the sizeable industries, hydropower adoption leads to 2.9 percentage points higher manufacturing employment share.

Table 3 suggests that there is no relationship between hydropower potential and sector employment in the period before the technological breakthrough. However, for each of the decades following the technological breakthrough, the reduced form result shows a positive impact of hydropower potential on the manufacturing employment share (see

Column (2) of Table 5). Specifically, a standard deviation increase in hydropower potential corresponds to a 0.4- to 0.7-percentage-point increase in the manufacturing employment share in each decade.[24] The reduced form specification possesses several beneficial properties compared to the FE+IV specification. It is a less elaborate estimation strategy and it is not dependent of the accuracy of the historical hydropower plant data, which might be somewhat imprecise in respect to timing of construction and location.

Estimates of the change in the employment share in services are not very robust across specifications, as seen in Table 4. The OLS result in Column (7) suggests an increase of 1 percentage point in the employment share in services in hydropower municipalities. The FE specification does not provide a significant result, while the FE + IV specification yields a negative result (at 10-percent confidence). The reduced form results in Table 5 are also not very clear, with a slight negative effect in the decade preceding 1910.[25]

The greatest employment share change is found for the primary sector. The OLS and FE specifications in Columns (10) and (11) of Table 4 suggest decreases of 9.4 and 4.1 percentage points in the primary sector employment share in hydropower producing municipalities, respectively. The FE + IV coefficient of hydropower is also negative but not statistically significant. The reduced form results suggest that there may be a decline in this sector in two of the three periods with the technology available. Investigating the change in the number of workers in the primary sectors in Online Appendix Table D.4, the decline is substantial and highly significant. Overall, the results suggest hydropower-induced structural transformation with a decline in the primary sector, while the size of the manufacturing sector increases.[26] IV + FE estimations provide rather imprecise results, but the conclusions are supported by the reduced form results and the results from the change in the number of workers in each sector in hydropower municipalities.

[24] We can make numerical examples using the lowest and highest categories of river flow in rivers of sufficient slope. For average municipality size (654 km^2), an extra 65,400 meters of low-flow river (10 m^3/s) or an extra 872 meters of high-flow river (750 m/s) in the municipality increases manufacturing employment share in each period with about 1–1.7 percentage points.

[25] The results do not include the category profession work. We have data on that category from 1900 on, and OLS and FE results from Online Appendix Table D.7 suggest that the share and number of professionals were rising.

[26] The results are similar when we include city municipalities in the sample in Online Appendix Table D.3, and the FE + IV specification for changes in the manufacturing employment share is significant. However, we are more concerned about confounders and sorting in an urban environment. We also carry out simple suggestive synthetic control estimations and arrive at similar conclusions in Online Appendix D.3.

OCCUPATIONAL MOBILITY IN HYDROPOWER MUNICIPALITIES

Upward Occupational Mobility over Careers and Generations

The previous section shows how the adoption of hydropower technology in early twentieth-century Norway was linked to structural transformation at the local level. Before this second wave of industrialization, the mostly agrarian economy of rural areas offered little opportunity for occupational mobility. That might have changed with the hydroelectric technology breakthrough, adoption of these techniques, and the concomitant industrialization process.

Panel A of Table 6 shows the estimated probability of upward occupational mobility for unskilled workers, depending on the hydropower status of the municipality. We compare an individual's stated occupation in the 1900 census with the occupation stated in the 1910 census. For unskilled workers, we define "upward mobility" as transitioning to a skilled manual occupation or a white-collar occupation.

In the OLS estimation in Column (1), the unskilled workers display a higher propensity for upward occupational mobility as a result of hydropower production in the municipality.[27] The adoption of hydropower technology translates into a 5-percentage-point higher probability of upward mobility. There is no significant relationship between upward occupational mobility and hydropower adoption for farmers and skilled workers (see Online Table D.10). For farmers, owning and renting land is presumably a disincentive for occupational movement. For skilled manual occupations, the insignificant result may reflect increased employment in manufacturing and services, rather than a general shift to occupations of even higher status.[28]

As mentioned earlier, the endogenous location 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 1900 with hydropower potential. With IV estimation in Column (2), the point estimate of hydropower production almost triples, to 14 percentage points. However, the standard errors are also inflated, so that the IV estimates might just be slightly higher than the OLS estimates. The larger effect might be a product of attenuation bias in the OLS estimates. However, we believe that it is more likely related to catch-up. The complier municipalities may have a larger potential for upward mobility

[27] The results in Column (1) are very similar with probit estimation (available on request).

[28] The conclusions from the analyses on upward mobility hold when a specification with number of hydropower plants in the municipality is used instead of binary hydropower status.

TABLE 6

UPWARD MOBILITY FOR UNSKILLED WORKERS IN HYDROPOWER MUNICIPALITIES. BASELINE AND SENSITIVITY OF RESULTS

	Baseline		Slope and Precipitation		Pre-Trend in Mobility		Treatment on 1910 Municipality	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Unskilled Manual Workers from the Linked Worker Sample								
Hydropower production	0.05***	0.14**	0.06***	0.12**	0.03**	0.12*	0.18***	0.16**
	(0.02)	(0.06)	(0.02)	(0.05)	(0.01)	(0.06)	(0.03)	(0.08)
Intergenerational mobility, 1865–1900					0.15***	0.14***		
					(0.02)	(0.02)		
First-stage F-value	—	17.05	—	18.95	—	16.22	—	37.88
Adjusted R^2	0.04		0.04		0.04		0.05	
N	30,824	30,824	30,824	30,824	28,996	28,996	30,824	30,824
Panel B: Sons of Unskilled Manual Workers from the Linked Father-Son Sample								
Hydropower production	0.11***	0.22	0.11***	0.13	0.10**	0.11	0.24***	0.27**
	(0.04)	(0.17)	(0.04)	(0.13)	(0.04)	(0.16)	(0.03)	(0.13)
Intergenerational mobility, 1865–1900					0.39***	0.39***		
					(0.05)	(0.05)		
First-stage F-value	—	12.21	—	12.84	—	11.43	—	17.63
Adjusted R^2	0.06		0.06		0.07		0.07	
N	10,542	10,542	10,542	10,542	10,149	10,149	10,542	10,542

Notes: Data from Norwegian censuses of 1900 and 1910. Panel A displays results for unskilled manual workers in the linked worker sample, while Panel B shows results for unskilled manual workers in the linked father-son sample. Columns (1) and (2) provide baseline results. In Columns (3) and (4), we control for the share of land with a gradient of more than 4 degrees and average precipitation in the municipality. In Columns (5) and (6), historical intergenerational mobility (1865–1900) is added. In Columns (7) and (8), hydropower status is allocated to municipality of residence in 1910. In the regressions, we control for the following characteristics of worker (son) in 1900: 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, infrastructure variables, emigration share, and county FE. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

if the drivers of endogenous location of hydropower plants are correlated with higher upward mobility in an earlier period for non-compliers.

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: whether a son displays upward occupation mobility relative to his father's occupation. We expect intergenerational mobility to be less restricted by the timing of treatment; consequently, we expect the coefficients to be higher. As can be seen from Columns (1) and (2) in Panel B of Table 6, that is the case. In the OLS specification, intergenerational upward mobility is over twice as large as intragenerational mobility. Similarly, IV estimation yields an estimate that is 8 percentage points higher but not statistically significant. There are not many unskilled fathers in hydropower municipalities in the sample (4.6 percent), which might explain the imprecise estimate.

The upward occupational mobility of unskilled workers in hydropower municipalities may be related to increased demand for skills. 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 that covered by 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 during the decade, if other specific skills could be acquired by means of on-the-job training.

There are several ways in which we can investigate the results further. 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 Columns (3) and (4), we control for measures of average gradient and precipitation, effectively identifying changes in hydropower status from river features that are conditioned on general municipality geography. The results are robust to these inclusions.

Because of the cross-sectional structure of the data, we are not able to observe directly whether hydropower-adopting municipalities displayed a positive pre-treatment trend in upward mobility. The best we can do is 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 municipality, we calculate the average likelihood of upward mobility. This variable is then included in Columns (5) and (6) of Table 6. The estimated coefficients of upward mobility are slightly lower for all specifications, but the overall conclusions are not changed by the inclusion of municipality-level historical mobility trends. All trends are positively and strongly correlated with mobility.[29]

Occupational and Geographic Mobility

The propensity for upward mobility may be different for locals and newcomers, for instance, if locals have established networks that can assist in job search or if movers are a selected group with superior ability that makes them more sought after. This issue has implications for the allocation of treatment. In Columns (7) and (8) of Table 6, we allocate treatment to the 1910 municipality of residence, instead of the 1900 municipality. Rather than belonging to the control group, workers relocating to hydropower municipalities between 1900 and 1910 contribute to the effect. In the OLS specifications in Column (7), the estimated coefficients are higher, in line with the selected mover hypothesis. In Column (8), the IV estimate for unskilled workers is not significantly different from the baseline. However, the corresponding estimate for the father-son sample is relatively higher and significant. The latter result probably reflects both selection and that there are initially few unskilled fathers in the rural municipalities that adopt hydropower technology.

To further study selection, we investigate how the propensity for upward mobility from unskilled status in our two samples is dependent on the geographical mobility and hydropower status of the sender and receiver municipalities. The results are displayed in Table 7. Relative to stayers in non-hydropower municipalities, stayers in hydropower adopting municipalities have 6- and 12-percentage-point higher probabilities of upward mobility in the linked worker and linked father-son samples, respectively. Movers have about a 20-percentage-point higher probability of upward mobility compared to stayers in non-hydropower municipalities, with approximately a doubling of this probability if the person moves into a hydropower municipality instead of a non-hydropower municipality.

[29] While we acknowledge that there are challenges involved in comparing historical mobility data over a longer timespan than the 10 years in our baseline sample (and in particular in using intergenerational mobility as a control for within-worker mobility), because of data limitations, we are not able to construct a mobility control variable with a design more similar to our 1900–1910 variable.

TABLE 7
UPWARD MOBILITY FOR UNSKILLED WORKERS BASED ON GEOGRAPHICAL MOBILITY. INVESTIGATION OF SELECTION EFFECTS

	Linked Workers (1)	Father and Sons (2)
Stayers in non-hydropower municipalities	Reference category	
Stayers in hydropower municipalities	0.06***	0.12***
	(0.02)	(0.04)
Movers	0.19***	0.21***
	(0.01)	(0.02)
Movers into hydropower municipalities	0.23***	0.23***
	(0.02)	(0.03)
Adjusted R^2	0.09	0.11
N	30,824	10,542

Notes: Data from Norwegian censuses of 1900 and 1910. Column (1) displays upward occupational mobility for unskilled manual workers in the linked worker sample, while Column (2) shows results for unskilled manual workers in the linked father-son sample. Controls are the same as in Column (1) in Table 6. Estimator: OLS. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

The evidence suggest that movers are a selected group and/or relatively better matched to the labor market in destination municipalities and that there are better opportunities for advancement in hydropower municipalities.

The baseline effect can be interpreted as an intention-to-treat effect. Table 7 shows that movers into hydropower municipalities have a high propensity for upward mobility. In our baseline specification, this group does not contribute to the effect, as it is considered non-treated. The inclusion of this group in the regression attenuates the effect by increasing the probability of advancement for the overall group of non-treated. However, omitting this group from the regression seems unattractive, as stayers may also be selected on unobservables. Allocating treatment to the 1900 municipality of residence of the worker shifts movers into hydropower municipalities from the control to the treatment group. The effect of hydropower on occupational mobility also reflects positive selection, as the likelihood of advancement might be considered in the relocation decision. In a Lewis-style model of the economy, this latter effect, with selection included, might come closer to a general equilibrium effect. In that sense, the two approaches can provide upper and lower bounds for the impact of hydropower production on upward mobility.

TABLE 8
UPWARD OCCUPATIONAL MOBILITY FOR THE UNSKILLED GROUPS WITH DIFFERENT TREATMENT INTENSITY

	Treatment Intensity in Megawatts			
	MW (1)	MW/km² (2)	MW/ Population in 1900 (3)	MW/ Population Density (4)
Means and Standard Deviations of Independent Variables of Interest				
Panel A	6.711	0.029	0.002	1.273
	(9.936)	(0.080)	(0.003)	(2.803)
Panel B	7.248	0.025	0.002	1.469
	(10.407)	(0.067)	(0.003)	(2.944)
Panel A: Linked Worker Sample				
Megawatt treatment	0.003***	0.052	6.336*	0.016***
	(0.001)	(0.132)	(3.127)	(0.004)
Adjusted R^2	0.03	0.02	0.03	0.03
N	1,217	1,217	1,217	1,217
Panel B: Linked Father-Son Sample				
Megawatt treatment	0.006***	0.734**	20.730***	0.033***
	(0.001)	(0.347)	(4.216)	(0.008)
Adjusted R^2	0.02	0.01	0.03	0.02
N	457	457	457	457

Notes: Data from Norwegian censuses of 1900 and 1910. Panel A displays results for unskilled manual workers in the linked worker sample, while Panel B shows results for unskilled manual workers from the linked father-son sample. 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 characteristics of workers (sons) in 1900: 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, infrastructure variables, and emigration share. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

Regional Heterogeneity, Treatment Intensity, and Timing of Plant Opening

Alternative tests of the estimates' robustness can be performed by investigating how the effects vary with treatment intensity. Using a publication by Den kgl. Vandfalkommission (1914), we can allocate power production (megawatts) in 1914 to all but 5 hydropower plants. In Table 8, we restrict the sample to municipalities with positive values of produced power. We experiment with different specifications of the variable based on megawatts 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 municipality heterogeneity might affect the result. For the linked worker sample in panel A, the level of megawatts and megawatts relative to municipality size and municipality population density in 1900 yields positive results. Using the result in Column (1) of panel A, we derive that increasing the megawatts produced by one standard deviation increases the probability of upward mobility by 0.03 percentage points. The same conclusions hold when the linked father-son sample is used (panel B), where all specifications are positive and significant at the 5 percent level. The effects are larger in the father-son sample than in the linked worker sample, indicating less adjustment costs across generations than across careers.[30]

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.

The record does not usually 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 fairly rapidly, we still cannot observe how the labor markets were affected by signals and expectations of a booming local 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 conduct occupational changes. Both timing effects provide a downward bias, suggesting that we estimate a lower bound for the effects. We investigate these issues in Table 9.

In Columns (1) and (2), we allocate treatment on the basis of opening years of the plants and exclude observations that are in municipalities that receive treatment earlier or later in the 1900–1909 period. The variable of interest is then an indicator that is equal to unity if plants were 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 coefficients, the occupation groups show a higher

[30] In each specification in Table 8, the variable of interest is scaled differently, causing the point estimates to vary. However, we obtain comparable results across specifications by calculating effect sizes using standard deviation changes to the variables of interest.

TABLE 9
TIMING OF HYDROPOWER ADOPTION AND THE LIKELIHOOD OF UPWARD MOBILITY

Plant Opening	1900–1905 (1)	1906–1909 (2)	1910–1912 (3)
Panel A: Unskilled Manual Workers, Linked Worker Sample			
Hydropower production	0.06*** (0.02)	0.05** (0.02)	0.05*** (0.02)
Adjusted R^2	0.04	0.03	0.04
N	30,051	30,362	29,589
Panel B: Sons of Unskilled Manual Workers, Father-Son Sample			
Hydropower production	0.16*** (0.05)	0.08 (0.06)	0.10*** (0.03)
Adjusted R^2	0.06	0.06	0.06
N	10,252	10,371	10,081

Notes: Data from Norwegian censuses of 1900 and 1910. Panel A displays results for unskilled manual workers in the linked worker sample, while Panel B shows results for sons of unskilled workers in the linked father-son sample. Dependent variables: indicators of upward mobility. Variable of interest: indicator of hydropower production in the years in question. Estimator: OLS. Controls are the same as in Column (1) in Table 6. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

effect from treatment in the early period (1900–1905) than in the later period. The result for the father-son sample in the later period is not significantly different from zero. In Column (3), the variable of interest is given as treatment in the years immediately after 1909. 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.

Did Upward Occupational Mobility Cause a Hollowing Out of the Skill Distribution?

So far, we have established that upward occupational mobility improved substantially for workers in manual unskilled occupations when hydroelectricity was established. This is in line with the results of Goldin and Katz (1998) using U.S. data for the early twentieth century, showing that technology has a skill bias. Recent works have found that technological change may contribute to a hollowing out of the occupation distribution (Gray 2013; Katz and Margo 2014). We investigate whether this is also

TABLE 10
HYDROPOWER ADOPTION AND CHANGE IN WORKER OCCUPATION SHARES

	Lowest Skilled (1)	Low Skilled (2)	Medium Skilled (3)	High Skilled (4)	Highest Skilled (5)
Summary statistics, 1900					
Mean	20.58	55.89	11.96	1.68	9.89
(std. dev.)	(11.87)	(17.93)	(8.92)	(1.79)	(6.97)
Summary statistics, change between 1900 and 1910					
Mean	–9.38	13.41	–3.4	–0.32	–0.32
(std. dev.)	(7.93)	(9.29)	(4.42)	(1.35)	(3.87)
Regression results, change between 1900 and 1910					
Hydropower production	4.11***	–6.50***	1.02	–0.93	2.30**
	(1.04)	(1.82)	(1.11)	(0.67)	(1.01)
Adjusted R^2	0.34	0.34	0.21	0.03	0.12
N	452	452	452	452	452

Notes: Data from Norwegian censuses of 1900 and 1910 are used to create a linked sample of workers belonging to detailed occupational categories. The five occupation classes are derived using the SEIUS measure. The measure ranks occupations using U.S. data on income and education from 1950. The classes have the following cutoffs: 9, 15, 20, and 25. Means and standard deviations for occupation shares in 1900 and change in occupation shares between 1900 and 1910 are provided in the top two panels. The lower panel shows regressions results where the variable of interest is obtaining hydropower status between 1900 and 1910. Municipalities that received this status earlier are omitted. Estimator: OLS. Dependent variables: change in detailed occupation shares between 1900 and 1910, in percent. In the regressions, we include an indicator of coast, area of land, share of emigrants in the decade preceding 1900, historical infrastructure variables, and county FE. Robust standard errors are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

the case for Norway in the early twentieth century. We go beyond the two-way grouping of manual occupations used in the previous section and rather apply the Duncan Socioeconomic Index (SEI) to the individual occupation codes to obtain a status rank for each individual.[31] Based on these values, we split the sample of workers into five status classes, which are further described in Online Appendix Section A.5.

We start by examining the overall changes in the occupational distribution for rural Norway as a whole. The distribution of the workforce across five skill categories in 1900 is given in the first row of Table 10, while the second row describes the change from 1900 to 1910. In the

[31] The SEI indicator is based on typical income and education scores for each occupation, from 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. Unfortunately, no indicator based on Norwegian data is available for the relevant period. However, we return to an alternative status indicator below.

aggregate, there is no hollowing out; over time, there is an increase in the share of individuals in the second-lowest skill category and a decrease in the lowest category.[32]

Of more interest, however, is a comparison of the municipalities that obtain hydroelectric plants between 1900 and 1910 and those that do not, using the specification in Equation (3). The coefficient on hydroelectricity is shown in Table 10. In this comparison, there is evidence of "relative" hollowing out, in that the lowest- and highest-skilled groups increase more in size when hydroelectric plants are established. The other groups have negative or small growth in employment shares, and the difference is statistically significant. If we instead restrict our analysis to only manual occupations (shown in the Online Appendix), the pattern is less clear with a statistically significant increase also in the medium-skilled category (with negative coefficients for the second and fourth categories).

We also investigate how the mobility responses to the new technology differ across the skill distribution, as measured by the share of individuals with manual occupations in each category that move to a higher-ranked occupation. As can be seen from Panel A in Table 11, there is little systematic variation in upward mobility across skill groups. There is a positive and significant upward mobility coefficient for those in the second lowest skill category in both samples. However, for the linked sample, the coefficient is not significantly larger than that for the lowest-skilled group. Moreover, the results are somewhat sensitive to the regression specification and choice of control variables. For this reason, we cannot conclude that the introduction of this new technology in the early twentieth century was associated with any hollowing out of the skill distribution.

The conclusions are similar when a different occupational status measure based more directly on (U.S.) wages, OCSCORUS, is used. Online Appendix Table D.12 replicates Table 11 for this measure and shows statistically significant coefficients of hydropower establishment for the "low" and "medium" skill categories, as well as for the lowest skilled in the linked sample. To conclude, while there are some indications of asymmetric differences across the skill distribution in response to new technology, we do not find any decisive evidence that some groups are systematically left behind.

[32] In Table 10, all skill categories are included; farmers are in the second-lowest skill category, while white-collar occupations are in the highest skill category. A similar table only for the manual occupations is provided in Online Appendix Table D.11.

TABLE 11
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	–0.01	0.05**	0.01	0.02
	(0.02)	(0.02)	(0.01)	(0.03)
Adjusted R^2	0.04	0.02	0.01	0.01
N	17,297	14,152	11,460	1,622
Panel B: Sons of Unskilled Manual Workers from the Linked Father-Son Sample				
Hydropower production	0.06	0.09**	–0.01	0.07
	(0.06)	(0.05)	(0.02)	(0.06)
Adjusted R^2	0.15	0.05	0.03	0.03
N	2,404	8,243	3,648	463

Notes: 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 four different skill classes. The skill classes are derived using the SEIUS measure. The measure ranks occupations using U.S. data on income and education from 1950. The classes are based on the following cutoffs: 9, 15, 20, and 25. Controls are the same as in Column (1) in Table 6. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations from Statistics Norway, IPUMS, ICPSR, and the Norwegian Water Resources and Energy Directorate. See text and Online Appendix A for further details.

CONCLUDING REMARKS

As technological change often takes place gradually, it is difficult 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 forming realistic expectations of 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 the impact of the shift to hydropower outside the setting of the core industrializing countries, and there is little evidence 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 was not distributed equally across the country. Hydropower municipalities experienced structural transformation; the manufacturing sector grew at the expense of the primary sector. Manufacturing employment growth is in line with what is found in the related literature (Kline and Moretti 2014), whereas the same strand of literature tends to find positive employment results for the primary sector. A possible explanation is that expansion in this sector was demanding, employment in the agricultural sector in rural areas was already high, and land may have been scarce (something the emigration in this period testifies to) and made scarcer by competing sectors. The Norwegian experience suggests that the new energy technology shifted local labor markets to industrial sectors.

The findings indicate that the adoption of hydropower technology and the concomitant industrialization process had an equalizing social gradient, as they caused upward mobility of workers and families at the low end of the skill distribution. Specifically, manual unskilled workers experienced upward occupational mobility and sons of unskilled workers experienced upward intergenerational mobility.

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 unskill-biased framework of nineteenth-century Great Britain. Acemoglu (2002) argues that the difference between the two can be partly 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 interpretation of these observations is that the changing occupational distributions reflect a reallocation of a population with basic skills from unskilled to skilled occupations. While we do not know the details of this reallocation, there are several possible channels that could be investigated with other sources of data, such as how important literacy was, the role of formal training, and to what extent workers were trained on the job. The specific case of hydroelectricity and industrialization may not be directly applicable to present-day industrializing countries, as long-run transmission of electricity through high-voltage lines is now routine. The results do, however, paint a clear picture of industrialization at the turn of the twentieth century as skill biased and with substantial positive effects, increasing social mobility.

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Online Appendix to

"Who benefited from industrialization? The local effects of hydropower technology adoption in Norway"

by Stefan Leknes and Jørgen Modalsli

This version: August 25, 2019

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 of hydropower adoption 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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Kjosbakken, E. (1973). *Mesna: kraftkilde, industriåre, kunstnermotiv, vannkilde, fiskeelv: utgitt ved Mesna kraftselskaps 50 års jubileum 1973*. Lillehammer

Kvinlaug, S. (1998). *Trælandsfoss 100 år: 1898-1998*. Kvinesdal: Trælandsfos A/S

Lange, E. (1985). *Fra Linderud til Eidsvold Værk IV. Treforedlingens epoke 1895-1970*. Oslo: Dreyers forlag

Lorentzen, B. (1966). *Vaksdal Mølle 1866-1966*. Bergen: J. W. Eide

Lund, T. (1991). *Elkrafta i Modum: Modum elverk 80 år: 1913-1993*. Vikersund: Elverket

Myrvang, C. (2014). *Troskap og flid. Kongsberg våpenfabrikks historie 1814-1945*. Oslo: Pax

Møller, I. (2002). *Norske vannkraftverk*, Vol. 1. Lysaker: Energi Forlag

Møller, I. (2003). *Norske vannkraftverk*, Vol. 2. Lysaker: Energi Forlag

Omang, R. (1935). *Fritzøe i slekten Treschows eie: 1835-1935*. Oslo: Aschehoug

Schwartz, J. J. (1914). *Kongsberg Vaabenfabrik: 1814-1914*. Kristiania: Grøndahl

Solem, A. (1954). *Norske kraftverker, Teknisk ukeblad 100 års jubileum*. Oslo: Teknisk ukeblads forlag

Sælen, F. (1961). *Fossen og fabrikken: litt om sævereid og virksomheten der*. Bergen

Throndsen, L. (1968). *A.S. Solberg Spinderi 150 år*. Drammen: Solberg Spinderi

Vevstad, A. (1988). *AS Egelands verk: Tresliperi 1888-1988*. Søndeled: Egelands Verk

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.

In the analysis in Table 3 of the main paper, the relationships between the instrument and changes between 1891 and 1900 to labor force size and sector employment shares, the municipality of Askim is excluded. This is one of the municipalities where year of construction is available (1900-1903). The information is available in the following publication:

Norges vassdrags- og elektrisitetsvesen (1922). *Utbygget vannkraft i Norge: En forelbig oversikt.* Kristiania: H. Aschehoug & co

A.2 Historical infrastructure data on municipalities

The data on infrastructure up until 1880 is taken from the collection "Norwegian Ecological Data, 1868-1903", compiled by Frank H. Aarebrot. This collection is available as data set 41 from the Inter-university Consortium for Political and Social Research (ICSPR), `https://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/41`. The infrastructure data are in Part 4 of the collection and refer to 1880 (though using the 1868 municipality structure, which we convert to the 1900 structure used in our paper). The variables used, and their description in the data set (Aarebrot uses "commune" for municipality, and "diligence" for coach), are:

- Existence of a pier where steamships would stop on a regularly scheduled basis in the commune
- Existence of a railway station in the commune
- Communes having one stop on steamship route 6 (the main coastal steamship route)
- Existence of a diligence stop in the commune

We update this information to 1890 using information found in the following publications:

Aspenberg, N. C. (1994). *Glemte spor: Boken om sidebanenes tragiske liv.* Mesna: Mesna trykk

Bergh, T. (2004). *Jernbanen in Norge 1854-2004: Nye spor og nye muligheter 1854-1940.* Bergen: Vigemostad & Bjørke AS

Bjerke, T. and F. Holom (2004). *Banedata 2004: Data om infrastrukturen til jernbanene i Norge.* Trondheim: Skipnes AS

Gibberud, I. J. and H. Sunde (1992). *Flåmsbana: Historien om en av verdens bratteste jernbaner.* Bergen: John Grieg Forlag

Hartmann, E., Ø. Mangset and Ø. Reisegg (1997). *Neste stasjon: En guide til jernbanens arkitekturhistorie*. Oslo: Gyldendal norsk forlag ASA

A.3 Sector composition data for municipalities

The data on sector composition between 1891 and 1920 are taken from the Norwegian Center for Research Data, NSD (*Kommunedatabasen*, `http://www.nsd.uib.no/kdb`) and contains a transcription of municipality-level results published in the original census reports.

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. Consequently, the categories for the oldest census in 1891 to a large extent determine the grouping of professions in each sector. The data are reported for individuals aged 15 years or older. We distinguish between three sectors: primary sector, manufacturing and services.

The data consist of variables where workers are allocated to subsectors on the basis of occupation. The categories that comprise the primary sector, manufacturing and services are given in Tables A.1, A.2 and A.3, respectively. The categories in the four censuses are alike with some minor exceptions, and therefore the baseline specification uses variation between all four censuses. The importance of the small discrepancies between censuses is evaluated through robustness tests. The categories are chosen to maximize comparability. In the baseline we aggregate to larger sectors to minimize the potential changes in categories and recording practice between censuses.

In the 1920 census, sector affiliation is based on belonging to a household. Moreover, while the 1891-1910 censuses base their tabulations on individuals present at the day of count (de facto population), the 1920 census tabulations are rather based on individuals' registered residency municipalities (de jure population). According to the documentary material from the 1920 census, the difference between the two definitions should be negligible. Nevertheless, to deal with this we exclude occupational groups whose geographical work location may create large discrepancies between the two count systems, for instance people like sailors who work in maritime sectors. In robustness tests we exclude the data from the 1920 census altogether with small changes to the overall conclusions (see Table D.6). Defining the manufacturing sector narrowly still yields significant results.

The primary sector consists of occupations in the following areas: farming and animal husbandry, horticulture, forestry and hunting, and fisheries. The manufacturing industry consists of factory industry, mining and quarrying, artisan industries and other smaller industries (works, construction and communications). Workers in smaller works and construction of communications are not included in a separable category in 1891 census. The census fixed effects should absorb this difference, as long as the geographical distribution of this category in 1891 is uncorrelated with hydropower production. The IV approach also assists as long as the locations of the omitted group are not correlated with the instrument. As a robustness test we let manufacturing industries consist of factory industry, mining and quarrying. This is a definition that may be more stable across censuses. The conclusions are robust to this alteration of definition (see Tables D.6 and D.5).

The service sector consists of commerce, trade, banking, the running of hotels and restaurants, and transportation. Profession work (civil administration, defense, the courts, teaching, health, art and literary work, and religious professions) are available from 1900. As can be seen in Table D.7, the profession work share is positively related to hydropower adoption, but not significant in the FE+IV specification. It is however significant when we drop 1920 also. There are also some issues concerning workers in the post and telephone sector in 1891. We therefore exclude the 1891 census also from the baseline specification in the same table without altering to the conclusions. Throwing out census years is a rather harsh robustness test as the categories missing in the variables probably represent small groups for which it is not likely that distribution is correlated with hydropower technology.

We also rerun the analyses without the census years 1891 and 1920, and without municipality fixed effects. The identification assumption must then be somewhat adjusted, stating that the instrument is also independent of municipality fixed effects. As can be seen from Table D.8, we obtain similar conclusions.

Table A.1: Primary sector variables

Census year	Rural/ urban	Category
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

Table A.2: Manufacturing sector variables

Census year	Rural/ urban	Category
1891		Manufacturing industry
		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

Table A.3: Service sector variables

Census year	Rural/ urban	Category
1891		Trade and banking
		Hotels and restaurants
		Transportation: trains and land-carriage
1900		Trade, banking and transportation (excluding sea transport)
1910	Rural	Trade, banking and transportation
		Trade: sales assistant
	Urban	Trade: merchants, wholesalers
		Trade: sales assistant
		Trade, banking and transportation: others
1920	Rural	Trade activity
		Transportation: carriers, chauffeurs etc. (excluding sea transport)
		Train, post and telegraph etc.
	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.

A.4 Individual-level data

The individual-level census records from 1865, 1900 and 1910 can be obtained from `http://www.nappdata.org`. More information on variable usage and linkage is given below in Appendix B.

A.5 Occupational classification

The occupational categories used in the baseline analysis are shown in Table A.4. Percentages refer to the share of the male population aged 20-50 in 1910.

In the section "Did upward occupational mobility cause a hollowing out of the skill distribution?", 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.

The lowest-skilled category (SEI 9 or lower) predominantly contains occupations classified as *manual, unskilled* in the baseline specification. The next category, SEI 10-15, contains *manual, unskilled* occupations, but also some *manual, skilled* occupations. *Farmers* are also classified in this category. Occupations in the next two categories, SEI 16-20 and SEI 21-25, predominantly constitute *manual, skilled* occupations in the baseline analysis. The highest-skill category, SEI 26+, also has a substantial share of *manual, skilled* occupations. In addition, nearly all white-collar occupations are placed in this category.

By way of illustration, the largest manual occupation groups are shown with SEIUS rankings and categories in Table A.5.

Table A.4: 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%
Salesmen, 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 occupational categories	8.1%
Total:	*13.6%*
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 occupational categories	22.0%
Total:	*32.1%*
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 occupational categories	8.0%
Total:	*27.2%*
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%
Total:	*23.2%*
Occupation missing	
Total:	*3.8%*

Table A.5: 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%
Husbandrymen or cotters	14	3.2%
Cotters 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.6 Summary statistics

Table A.6: 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	2.62	2.07
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.7: Summary statistics for municipality level analyses

	Hydropower municipalities				Non-hydropower municipalities			
	1891		1920		1891		1920	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Labor force size (pop. aged 15+)	2165.3	(1284.56)	3037.99	(2039.07)	1605.58	(900.86)	1857.8	(1332.76)
Employment share in manufacturing	10.95	(6.00)	16.15	(8.23)	7.48	(3.97)	8.83	(5.38)
Employment share in services	3.91	(5.34)	8.76	(7.07)	1.24	(2.62)	3.87	(3.63)
Employment share in primary sector	39.14	(7.97)	30.35	(9.87)	43.11	(7.85)	39.95	(9.05)

Municipalities are separated into two groups: municipalities with hydropower production sometime during 1891-1920 (hydropower municipalities) and municipalities without such production in the same period (non-hydropower municipalities).

Table A.8: 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 being resident 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
Steamship stop	0.62	0.49	86730
Ship route stop	0.2	0.4	86730
Railwaystation before 1880	0.14	0.35	86730
Number of railwaystations constructed 1880-1890	0.13	0.68	86730
Coach stop	0.05	0.22	86730

Table A.9: 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 municipality of residence	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
Steamship stop	0.62	0.49	50999
Ship route stop	0.2	0.4	50999
Railwaystation before 1880	0.14	0.34	50999
Number of railwaystation constructed 1880-1890	0.08	0.49	50999
Coach stop	0.05	0.21	50999

A.7 Incomes by occupational category

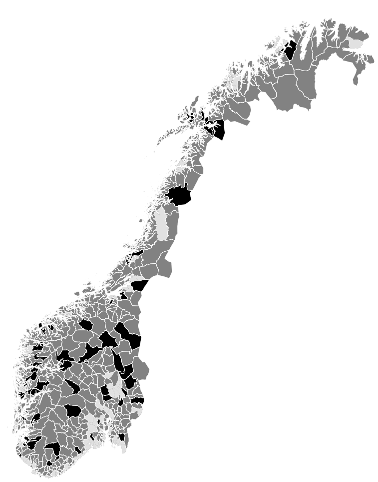
The income information in Footnote 14 of the main paper are calculated from data on income for men aged 30-60 in "Indtægts- og formuesforhold efter skatteligningen 1911 i forbindelse med Folketællingen 1910, Norges Officielle Statistik VI no. 24", publ. 1915. A general review of this documentation is given in Modalsli (2017), page 14 as well as in Appendix A2 to that paper (figure of general trends).

Figure A.1: City municipalities and municipalities with hydropower production by census year

(a) City municipalities, excluded from sample

(b) Hydropower production in 1900

(c) Hydropower production in 1910



(d) Hydropower production in 1920

B Supplementary information on record linkage

The linked 1900-1910 sample (as well as the 1865-1900 sample used for "historical mobility") was constructed on the basis of an algorithm developed and used by Modalsli (2017). The following exposition is based on the information in that paper, as well as its online appendix.

B.1 Data

Data were obtained from individual-level data sets of the population as recorded in the Norwegian censuses of 1865, 1900 and 1910.

From the census files, the following variables were extracted:

- First name
- Last name
- Name of place of residence
- Information on family relationship of those who reside together
- Birth year
- Municipality of birth

Then, individuals are linked across censuses by personal information: name, birth time and birth place. Time-varying characteristics such as occupation, spouse or other family members are not used for linkage as these are likely to be correlated with the outcome of interest. As fixed surnames were not mandated by law in Norway until 1925, there was still some flexibility in how individuals reported their identity to the authorities during this period. Spelling was somewhat flexible, and individuals could go by inherited surnames, patronymics (the name of their father plus the suffix "-sen"), or surnames based on the farms they grew up on. Over time, patronymics and farm names became fixed as time-invariant surnames that were inherited from fathers to sons.

The census files were obtained from the North Atlantic Population Project (www.nappdata.org). Names were converted to lower case; Norwegian characters were converted to "a" in all censuses (because of a limitation on how the characters were stored in the NAPP database at the time of extraction); special characters were removed and some common substitutions of spelling variants were substituted (such as "ch" for "k"). Patronymics were constructed by adding "sen" to the father's first name; the patronymic for the first names "Ola" and "Ole" was changed to the most common variant "Olsen".

B.2 Matching algorithm: Calculating differences in identifying information

Matches are in principle constructed by comparing all possible pairs from two years; however, this is impractical in practice because of the large number of potential combinations. To improve running time and improve flexibility in formulating match rules, all distances between match elements (e.g. names) were pre-calculated. For each piece of identifying information (as listed above) and year, a file with all unique occurrences was constructed. Then, all occurrences in year A were compared to all occurrences in year B for all variables. The following paragraphs describe how match scores are assigned; this description is partially reproduced from Modalsli (2017, Online Appendix B).

Strings (names)

The Levenshtein distance between any two strings is calculated using a command included in the `strgroup` package for Stata (written by Julian Reif, University of Chicago). The Levenshtein algorithm counts the minimum number of letter removals, additions or swaps needed to go from one string to another. The distance between the strings is divided by the length of the shortest string to get the final score. Only matches with name scores smaller than 0.3 are considered.

Scores are denoted D_F (first names), D_{L-CC} (last names), D_{L-PC} (patronymic in first period, last name in second period), D_{L-LC} (location name in first period, last name in second period), D_{L-CP} and D_{L-CL}.

Birth years

The score is the absolute value of the birth year in the two sources, and is considered if the difference is five years or less. The score is denoted D_Y.

Municipality of birth

Municipalities are aggregated to avoid mismatches due to border changes and mergers.

The score is set to 0 if the municipality cluster matches; 1 if the cluster is different but the county matches; 2 if both periods have missing birth municipality, and 3 if one of the periods has a missing birth municipality. The score is denoted D_M.

Aggregating match scores

Given the above qualifications, all matches between the compared censuses are considered. First, the two lists are merged by potentially similar first names ($D_F < .3$), then the scores for other matches are added. The last name score is constructed as $D_L = \min(D_{L-CC}, D_{L-PC}, D_{L-LC}, D_{L-CP}, D_{L-CL})$. Matches that are not considered (birth times too different or $D_L > .3$) are removed from the data set.

These scores are then combined to create an aggregate score. To balance the impact of name changes with differences in other characteristics, name differences are multiplied by 8.

$$D = 8 \cdot D_F + 8 \cdot D_L + D_Y + D_M \quad \text{(A1)}$$

The score D states the distance (difference) between two observations — one observation from each time period. Clearly, we want to pick the pairs of observations with low differences. However, we also have to evaluate the degree of *uniqueness* of each pair. For each observation i from time t, rank the candidates from period $t-1$ in descending order by score. Each $t-1$ candidate j will now have a difference score $D_{i,j}$. The uniqueness parameter R_i is then the difference between the (i, j) combination score $D_{i,j}$ and the score of the next best option (i, j'), $D_{i,j'}$. A higher value of R_i means the match is clearly better than other candidate matches. A similar uniqueness score R_j can be calculated from the viewpoint of the $t-1$ data set.

For a candidate to be accepted, restrictions are placed on the difference score and the uniqueness of each pair of observations. As the matching procedure is computationally intensive, a limited set of combinations is considered. Two different approaches with respect to uniqueness are tried; one where the limit of R increases with D (that is, more uniqueness is required if the match score is relatively poorer) and one where the limit of R is the same regardless of the requirement for D. In both cases, the match procedure is run iteratively; after each round, all accepted matches are removed, and the metrics are re-calculated.

The first round consists of all perfect matches: those where name, birthplace and birth time match perfectly ($D_{i,j} = 0$) and there are no other potential candidates for a match (that is, no candidate pairs where the composite scores are below the consideration thresholds described above).

From the second round onward, the allowable difference is increased in increments of 0.5. The allowable non-uniqueness is set to 0.5 for the second round and then increased by 0.25 in each iteration. Thus, the second round has the requirement $D_{i,j} \leq 0.5, R_i \geq 0.5, R_j \geq 0.5$, the third round $D_{i,j} \leq 1.0, R_i \geq 0.75, R_j \geq 0.75$ and so on. Visual inspection of the results show that the number of potential erroneous matches starts to appear around the sixth or seventh iteration. For this reason, the match procedure is stopped after round 5, the final requirement being $D_{i,j} \leq 2.0, R_i \geq 1.25, R_j \geq 1.25$.

B.3 Evaluating the matching algorithm

The details of the matching algorithm do not affect the mobility estimates. As shown in the online Appendix to Modalsli (2017), the Altham statistic (a commonly used mobility metric based on the full matrix of father-son occupations) hardly differs across data sets constructed with different ranges of parameters. Changing the matching parameters (accepting more or less matches) only changes the baseline estimate of 24.1 for the 1865-1900 period within a narrow range (from 4% below to 1% above).

As is common in matched samples of this type, some selection in matching cannot be completely ruled out. As mentioned in the main text, the main selectivity problem is with respect to farmers — there are higher success rates in matching individuals from this occupation group. This is not a major concern in this paper, as farmers are removed from the analysis of mobility by means of the linked data. Second, individuals from larger municipalities are harder to match (less unique identifiers); the baseline analysis here only encompasses rural areas (where most municipalities are relatively small).

C Supplementary information on estimation

C.1 Standard errors

Throughout the paper we compute heteroscedasticity robust standard errors clustered on the municipality level. This is motivated from potential correlations between components in outcomes within clusters. In the municipality analyses the number of fixed effects are high, as we include fixed effects for each municipality and census year. In addition, the number of observations within clusters in the balanced panel is low ($t = 4$). This causes the cluster robust variance matrix to become highly singular and nonsymmetric when conducting IV estimations.

This challenge to inference is described in detail in Cameron and Miller (2015), pages 330-331, where also a solution is proposed. The solution entails computing the Arellano (1987) cluster robust variance matrix. Properties are also described in Wooldridge (2010), page 275. In practice, this is equivalent to estimate the within estimator standard errors. To obtain reliable inference, we compute such standard errors in the municipality IV-regressions using the Stata command xtivreg2.

D Supplementary analyses and sensitivity tests

D.1 Reduced form results

Table D.1: Reduced form results

Sample:	Municipality sample								Linked samples	
									Workers	Father-sons
Dependent variables:	Ln(labor force)		Percentage of workers in						Upward mobility	
			Manufacturing		Services		Primary sector		for unskilled	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: unskilled manual workers from the linked worker sample										
Hydropower potential 1900	0.020	0.013	2.878***	1.732***	0.249**	-0.156	-2.216***	-0.954**		
	(0.029)	(0.019)	(0.544)	(0.652)	(0.112)	(0.097)	(0.491)	(0.370)		
Hydropower potential 1910	0.006	-0.002	2.109***	0.964**	0.123	-0.282*	-1.588**	-0.326	0.015***	0.023
	(0.031)	(0.019)	(0.673)	(0.377)	(0.095)	(0.154)	(0.688)	(0.405)	(0.006)	(0.017)
Hydropower potential 1920	0.009	0.001	2.276***	1.133**	0.021	-0.385	-2.245***	-0.981*		
	(0.039)	(0.034)	(0.657)	(0.441)	(0.134)	(0.235)	(0.761)	(0.560)		
County fixed effects	Y	N	Y	N	Y	N	Y	N	Y	Y
Municipality fixed effects	N	Y	N	Y	N	Y	N	Y	N	N
Adjusted R-Squared	0.32	0.96	0.29	0.74	0.36	0.67	0.37	0.76	0.03	0.06
N	1820	1820	1820	1820	1820	1820	1820	1820	30824	10542

Data from Norwegian censuses of 1891, 1900, 1910 and 1920. For the linked samples only the middle censuses are available. Columns (1)-(8) display the reduced form results of the municipality regressions. Columns (9)-(10) display the results of the linked samples of unskilled manual workers and fathers respectively. Dependent variables: potential labor force and sector sizes, and upward occupational mobility for workers and across generations. Variables of interest: hydropower potential per thousand (anchored to 1900 home municipality in linked samples). Estimator: OLS.

All specifications control for geographical size of municipality (km^2), indicators of coast, historical infrastructure variables and lagged emigration share. In columns (1)-(8) the regressions also control for year fixed effects. In columns (9)-(10) the regressions include 1900 worker (son) characteristics: age, age squared, indicator of being married, number of children, and indicator of not being resident in municipality of birth. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

D.2 Alternative regression specifications and robustness checks

Table D.2: Hydropower production and general population size

	ln(population size)		
	OLS	FE	FE + IV
	(1)	(2)	(3)
Hydropower production	0.40***	0.14***	-0.11
	(0.07)	(0.03)	(0.23)
Municipality FE	N	Y	Y
First-stage F-statistic	-	-	10.84
Adjusted R-squared	0.33	0.97	-
N	1820	1820	1820

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

Dependent variables: natural logarithm of population size. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicators of coast, historical infrastructure and lagged emigration share. Instruments are hydropower potential interacted with decade indicators. Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV-estimate follows Arellano (1987). Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table D.3: 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	0.44***	0.14***	0.01	7.25***	2.38***	6.04**
	(0.08)	(0.03)	(0.22)	(0.95)	(0.62)	(2.73)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	6.23	-	-	6.23
Adjusted R-squared	0.37	0.97	-	0.37	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.)	3.38	(3.25)		36.16	(11.68)	
Hydropower	1.24***	0.37	-4.42**	-8.63***	-3.19***	-3.17
	(0.37)	(0.23)	(1.87)	(1.20)	(0.69)	(3.27)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	6.23	-	-	6.23
Adjusted R-squared	0.37	0.85	-	0.44	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 are available for persons aged 15 and older. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicator of coast, infrastructure and lagged emigration share. Instruments are hydropower potential interacted with decade indicators. Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV-estimates follows Arellano (1987). Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table D.4: Hydropower effect on the level of sectoral employment. Dependent variables are standardized

	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)		56.86	(99.25)		673.34	(383.27)	
Hydropower plants	1.16***	0.53***	0.79*	0.74***	0.53**	-0.64	0.25*	0.02	-0.59***
	(0.19)	(0.18)	(0.44)	(0.18)	(0.21)	(0.64)	(0.13)	(0.04)	(0.22)
Municipality FE	N	Y	Y	N	Y	Y	N	Y	Y
First stage F-statistics	-	-	10.84	-	-	10.84	-	-	10.84
Adjusted R-squared	0.32	0.74	-	0.31	0.54	-	0.28	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, respectively. In the regressions variables are standardized to have a mean of zero and standard deviation of unity. Data on sectoral affiliation are only available for persons aged 15 and older. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), historical infrastructure, indicator of coast and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV-estimates follows Arellano (1987). Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table D.5: Hydropower production and changes in the traditional manufacturing and mining

	Percentage of workers in manufacturing, narrowly defined			Workers in manufacturing, narrowly defined		
	OLS	FE	FE + IV	OLS	FE	FE + IV
	(1)	(2)	(3)	(4)	(5)	(6)
Mean (std. dev.)	2.67	(4.35)		66.13	(160.38)	
Hydropower	6.19***	1.89***	2.86*	208.93***	118.09***	140.99*
	(1.03)	(0.55)	(1.54)	(33.69)	(34.06)	(75.54)
Municipality FE	N	Y	Y	N	Y	Y
First-stage F-statistic	-	-	10.84	-	-	10.84
Adjusted R-squared	0.31	0.82	-	0.29	0.73	-
N	1820	1820	1820	1820	1820	1820

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

Dependent variables: percentage and level of worker shares in manufacturing, narrowly defined as traditional manufacturing and mining. Data on sectoral affiliation is available for persons aged 15 and older. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicator of coast, infrastructure and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV-estimates follows Arellano (1987). Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table D.6: 1920 census excluded

	Manufacturing		Services	Primary
	Broadly defined	Narrowly defined		sector
	FE + IV	FE + IV	FE + IV	FE + IV
	(1)	(2)	(3)	(4)
Panel A: Percentage of workers				
Hydropower	6.37	3.57*	-2.73	-1.12
	(4.14)	(2.07)	(1.68)	(3.51)
First-stage F-statistic	9.84	9.84	9.84	9.84
N	1365	1365	1365	1365
Panel B: Number of workers				
Hydropower	220.34	130.32**	-35.23	-118.01
	(136.75)	(64.25)	(35.55)	(101.74)
First-stage F-statistic	9.84	9.84	9.84	9.84
N	1365	1365	1365	1365

Data: Norwegian censuses from 1891, 1900 and 1910.

Dependent variables: Panel A: percentage worker shares in manufacturing, services and primary sectors, while Panel B includes the level of the same variables. See Table D.5 for definition of the different manufacturing variables. Data on sectoral affiliation is available for persons aged 15 and older. Regressions control for year fixed effects, municipality fixed effects and lagged emigration share. Estimator: 2SLS. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV-estimates follows Arellano (1987). Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table D.7: Hydropower production and services sector changes, 1900-1920

	Workers in services				Workers in profession work			
	OLS	FE	FE + IV	FE + IV Omit 1920	OLS	FE	FE + IV	FE + IV Omit 1920
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Percentage of dependent variables								
Mean (std. dev.)	2.95	(2.19)		-	1.38	(0.55)		-
Hydropower	1.04***	0.42	-2.25	-1.88	0.26***	0.15**	0.19	0.61*
	(0.26)	(0.30)	(1.81)	(1.71)	(0.06)	(0.06)	(0.29)	(0.35)
First-stage F-statistic	-	-	6.58	7.81	-	-	6.58	7.81
Adjusted R-squared	0.35	0.71	-	-	0.22	0.66	-	-
N	1365	1365	1365	910	1365	1365	1365	910
Panel A: Level of dependent variables								
Mean (std. dev.)	66.09	(111.63)		-	28.26	(35.82)		-
Hydropower	71.15***	47.81**	-65.95	-24.58	24.14***	13.29**	-9.19	0.96
	(16.81)	(22.13)	(70.87)	(27.17)	(5.23)	(5.23)	(16.83)	(8.24)
First-stage F-statistic	-	-	6.58	7.81	-	-	6.58	7.81
Adjusted R-squared	0.32	0.62	-	-	0.26	0.74	-	-
N	1365	1365	1365	910	1365	1365	1365	910

Data: Norwegian censuses from 1900, 1910 and 1920.

Dependent variables: workers in services in columns (1)-(4) and workers in profession work in columns (5)-(8). In Panel A the variables are defined as percentages and in Panel B as level. Data on sectoral affiliation are available for people aged 15 and older. Regressions control for year fixed effects, county fixed effects, geographical size of municipality (km^2), indicator of coast, infrastructure and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

Robust standard errors clustered on municipality are in parentheses. The formulation of the cluster-robust covariance matrix for the IV-estimates follows Arellano (1987). Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table D.8: IV results without municipality fixed effects and excluding the 1891 and 1920 censuses

	ln(labor force size)	Percentage of workers			Number of workers		
		Manu.	Service	Prim.	Manu.	Service	Prim.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Hydropower	0.09	26.05***	1.73	-19.14***	512.63**	18.65	-365.89*
	(0.31)	(8.60)	(1.16)	(6.57)	(229.20)	(34.43)	(198.19)
First-stage F-statistic	9.46	9.46	9.46	9.46	9.46	9.46	9.46
N	910	910	910	910	910	910	910

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

Dependent variables: natural logarithm of the labor force size (inhabitants 15 years and older) in column (1). Percentage worker shares in manufacturing, services and primary sectors in columns (2)-(4), and the level of the same variables in columns (5)-(7). Data on sectoral affiliation are available for persons 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, infrastructure and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

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

Table D.9: IV results without municipality fixed effects

	ln(labor force size)	Percentage of workers			Number of workers		
		Manu.	Service	Prim.	Manu.	Service	Prim.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Hydropower	0.08	20.94***	0.70	-18.49***	505.81***	-7.24	-402.84**
	(0.31)	(3.87)	(0.90)	(4.59)	(125.25)	(47.12)	(182.26)
First-stage F-statistic	10.23	10.23	10.23	10.23	10.23	10.23	10.23
N	1820	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 column (1). Percentage worker shares in manufacturing, services and primary sectors in columns (2)-(4), and the level of the same variables in columns (5)-(7). Data on sectoral affiliation are available for persons 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, infrastructure and lagged emigration share. Instruments are hydropower potential interacted with decade indicators.

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

Table D.10: Relationship between hydropower production and upward mobility for different occupational 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		0.01	-0.01	0.05***	0.14**	0.00	-0.02
		(0.01)	(0.03)	(0.02)	(0.06)	(0.01)	(0.02)
First stage F-value		-	14.73	-	17.05	-	34.70
Adjusted R-squared		0.02	0.02	0.04	0.03	0.01	0.01
N		32904	32904	30824	30824	16193	16193
Panel B: Sample of linked father-son pairs							
Hydropower		0.09***	0.10	0.11***	0.22	0.01	-0.04
		(0.03)	(0.09)	(0.04)	(0.17)	(0.01)	(0.03)
First stage F-value		-	12.23	-	12.21	-	10.88
Adjusted R-squared		0.04	0.04	0.06	0.06	0.01	0.01
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 characteristics of workers (sons) in 1900: age, age squared, indicator of being married, number of children, and indicator of not being resident in municipality of birth. All regressions include indicators of coast, area of land, infrastructure variables, emigration share 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 D.11: Hydropower adoption and change in worker occupation shares, manual sample

	Lowest-skilled	Low-skilled	Medium-skilled	High-skilled	Highest-skilled
	(1)	(2)	(3)	(4)	(5)
Summary statistics 1900					
Mean	40.50	28.84	23.02	3.30	4.34
(std. dev.)	(21.95)	(26.92)	(15.33)	(3.55)	(4.55)
Summary statistics change					
Mean	-7.64	4.75	0.29	0.60	2.00
(std. dev.)	(11.77)	(10.38)	(9.24)	(3.37)	(4.97)
Hydropower	2.56	-5.67***	3.90**	-2.22*	1.42
	(1.83)	(1.77)	(1.79)	(1.16)	(1.24)
Adjusted R-squared	0.19	0.16	0.09	0.02	0.06
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 occupation shares between 1900 and 1910, in percent. The five occupation classes are derived using the SEIUS measure. The measure ranks occupations using U.S. 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, historical infrastructure variables and county fixed effects. Robust standard errors are in parentheses. Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table D.12: Hydropower adoption and the likelihood of upward mobility for manual workers belonging to different skill classes, OCSCORUS measure

	Lowest-skilled	Low-skilled	Medium-skilled	High-skilled
	(1)	(2)	(3)	(4)
Panel A: sample of linked workers				
Hydropower production	-0.00	0.09***	0.10**	0.01
	(0.02)	(0.03)	(0.04)	(0.01)
Adjusted R-squared	0.03	0.04	0.07	0.02
N	11473	8545	11053	11680
Panel B: sample of linked fathers and sons				
Hydropower production	0.13*	0.16***	0.13*	-0.01
	(0.08)	(0.03)	(0.07)	(0.02)
Adjusted R-squared	0.09	0.20	0.14	0.03
N	881	7367	2315	3697

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 of manual workers belonging to four different skill classes. Five skill classes are derived using the OCSCORUS measure. The measure ranks occupations using U.S. 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, historical infrastructure variables and county fixed effects. Robust standard errors clustered on municipality are in parentheses. Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

D.3 Robustness of aggregate results using synthetic control methods

To test the robustness of the results using a different estimation approach, we proceed with a synthetic control method with multiple treatment municipalities (Cavallo et al., 2013).[1] 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. The following categories from 1865 are included to expand the trend:

Table D.13: Sector variables from the 1865 census

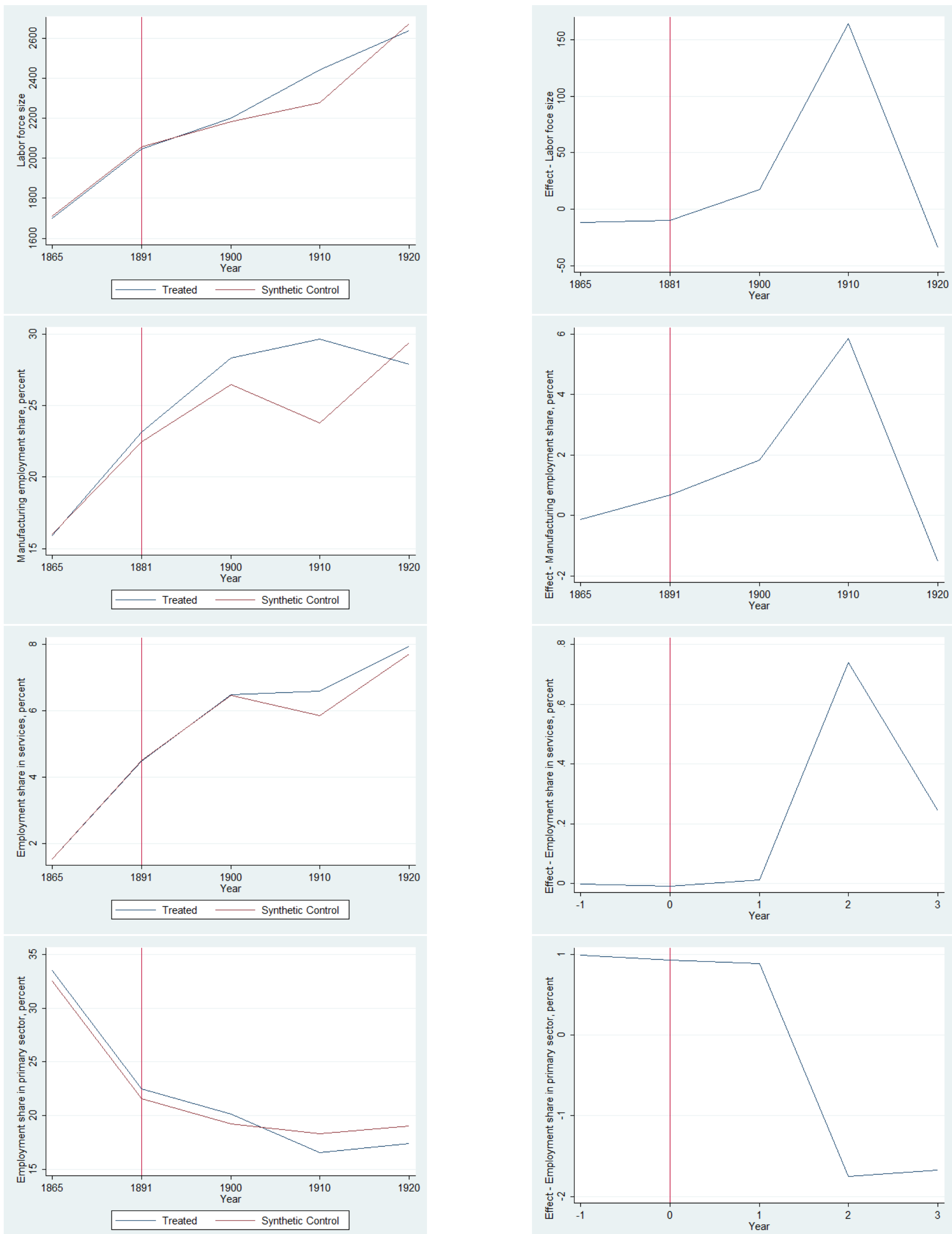
Sector	Rural/ urban	Category
Primary	Rural	Farming and animal husbandry, forestry, fisheries: main persons
		Farming and animal husbandry, forestry, fisheries: servants
	Urban	Farming and animal husbandry, forestry, fisheries: main persons
		Farming and animal husbandry, forestry, fisheries: servants
Manufacturing	Rural	Mining and manufacturing industry: main persons
	Urban	Mining and manufacturing industry: main persons
Services	Rural	Trade: Main persons
		Transport (excluding sea transport), post and telegraph: 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

The new data enable 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 replicate 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 D.2. 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

[1] We use the synth_runner package for Stata.

Figure D.2: Effect of hydropower technology adoption on labor force size and structural transformation with synthetic control method



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 the use of this method, and the results must be interpreted accordingly.

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