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

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## Abstract

This paper studies the impact of the construction of hydropower facilities on labor market outcomes in Norway at the turn of the twentieth century (1891-1920). The sudden breakthrough in hydropower technology provides a quasi-experimental setting, as not all municipalities had suitable natural endowments and the possible production sites 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 like productivity growth and higher incomes. On the other hand, benefits were not equally distributed, and there were short-term adjustment costs as well as a permanent loss of certain types of jobs. 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 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) and 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 the location of hydropower production, which displays no significant relationship with municipality pre-trends. We also apply fixed effect 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

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[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).

had undergone only a limited industrial revolution (Venneslan 2009). Over the next thirty years, more than 140 hydroelectric power plants would be constructed, mostly in rural areas. The technology was imported from abroad, and partly financed with foreign capital. The historical circumstances make it less likely that the results are affected by unobserved characteristics 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 tend 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 technology 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 U.S.) 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 U.S. in the first half of the 20th 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 U.S. in the 1930s. Studying the electrification of rural areas in the U.S. 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 1920-1940, 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 impose both local fixed effects and employ an instrumental variable 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 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

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[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).

[5] Much of this literature relates to the Industrial Revolution in Great Britain in the eighteenth century, e.g. 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 e.g. Clark, 2005; Allen 2009). There is disagreement as to whether wages can provide a good measure of the standard of living (Broadberry

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 utilizing 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 century, 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.

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 U.S. 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 U.S. (Modalsli 2017). To our knowledge, no previous studies have examined how intergenerational mobility is affected by place-specific technology and

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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 thirty-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 late twentieth-century U.S.

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 per cent of the population was employed in manufacturing, compared to 8 per cent in 1875 (Statistics Norway 1978, 36). Manufacturing was mostly an urban phenomenon; this is attributed by Hodne and Grytten (2000, 210) to several attractive non-agricultural employment options in rural areas, including fisheries and employment at sea.

Waterfalls had been utilized for economic production for a long time; sawmills powered by water ("oppgangssager") were established in the early sixteenth century (Helle et al. 2006, 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% and 5.8% in 1896 and 1905 to 44.6% and 79.8% 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 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

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[7] Regional studies of mobility and economic conditions are available for more recent periods, such as Feigenbaum (2015) (Depression-era U.S.) and Bütikofer, Dalla-Zuanna, and Salvanes (2018) (late 20th century oil boom in Norway).

[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).

of saltpetre 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 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 per cent of gross investment in the period 1895-1914, and 39 per cent of listed manufacturing firms were foreign-owned in 1909 (Hodne and Grytten 2002, 44). In 1909 85% of the capital in chemicals, 47% in electricity production and 44% 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 come from the legal realm. There were public reactions against foreign penetration in the economy around 1905 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, 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.

**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) |

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

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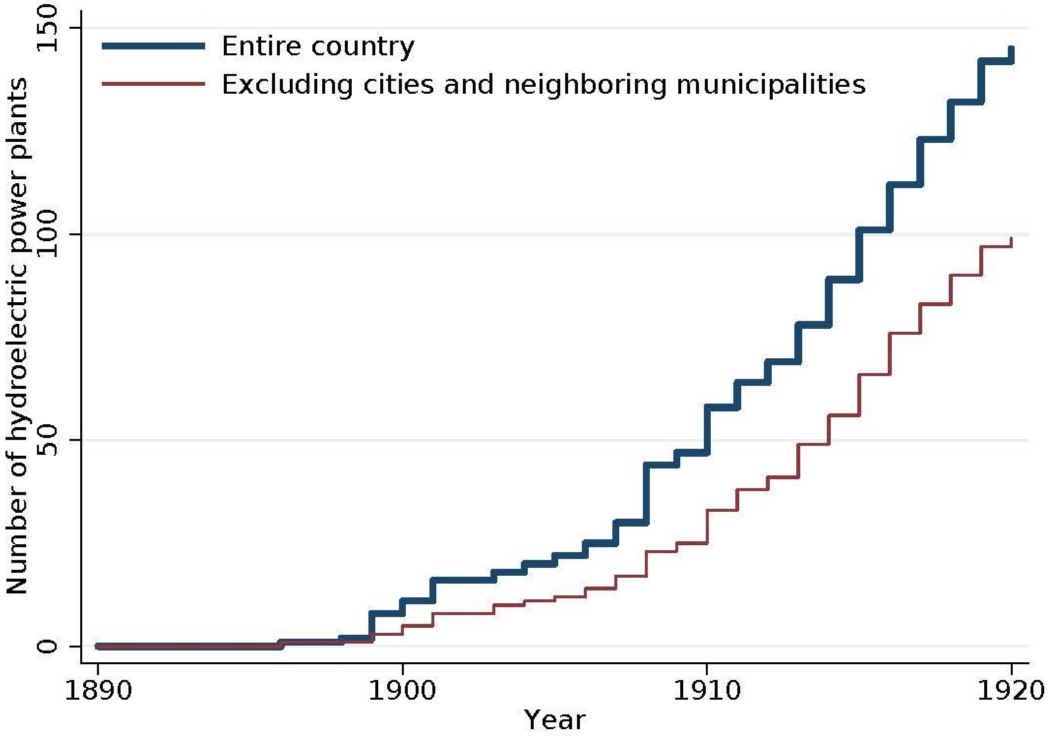
[9] For aggregate municipal data, we use digitized data made available by the Norwegian Center for Research Data (NSD). (NSD are not responsible for the analysis or interpretation of results based on the data they collect.) The aggregate analysis is based on the population aged over 15 years. Further 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.

[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.

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

**Figure 1: Number of hydropower plants, by year**



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 finally in 1920 there are 97 plants in 74 municipalities. The

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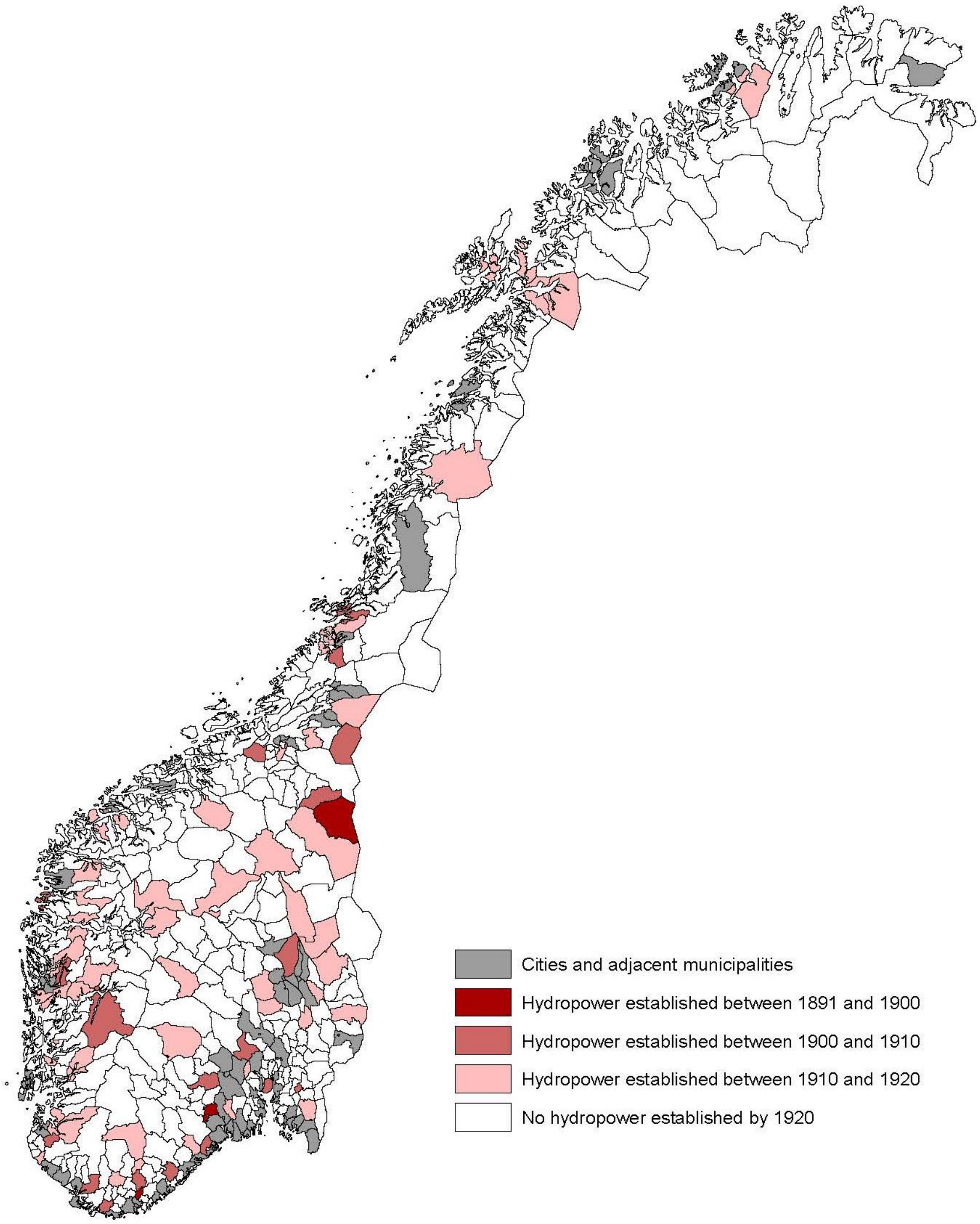
[12] Abramitzky, Boustan, and Eriksson (2012) do find evidence of negative selection from urban areas.

[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.

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

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



## 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 Integrated Public Use Microdata Series (IPUMS) (Minnesota Population Center, et al, 2017; The Digital Archive, et al, 2008, 2011). The records contain information on names, ages, places of residence and occupation (coded in the HISCO standard) of all individuals resident in Norway in those two years. 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 U.S. (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 (i.e. there are no other good candidates in either year for each of the observations). In this way, 44 per cent 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 individuals' occupational mobility (change in occupation over these ten years) for older individuals, and intergenerational mobility (comparison between the individuals' occupation and that of their fathers) for younger individuals. The 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 literature 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

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[14] A 1915 tabulation of incomes across census occupations indicates that incomes for men in manual skilled occupations in 1910 were 80 per cent higher on average than those 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% 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.

to Norway, knowing the "true" match shares (what one would get with 100% 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 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, $\beta_1$, by OLS:

$$y_{mt} = \beta_0^1 + \beta_t^1 + \beta_m^1 + \beta_1^1 HP_{mt} + \mathbf{X}_{mt}\boldsymbol{\delta}^1 + \epsilon_{mt}^1 \qquad (1)$$

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

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[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 same names born in the same year) and hence not be accepted by the matching algorithm.

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

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 fixed effects for each municipality ($\beta_m$). 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 fixed effects are replaced with 18 county fixed effects. $\beta_t$ represents census fixed effects and $\epsilon$ 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 description and tests of instrument relevance and excludability can be found in the next section. The identification assumption is that conditional on observed municipality characteristics, municipality and census fixed effects, 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 fixed effects. We expect the establishment of hydropower plants to follow a rational schedule where the most suitable locations are developed first; and, in subsequent steps, marginally less suitable locations follow. 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:

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

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:

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

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

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

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 fixed effects in the cross-section dataset. However, we can mitigate the influence of more aggregated area characteristics by adding county fixed effects $\beta_c$. In addition, we include the observed municipality characteristics ($\mathbf{X}_{m,1900}$) of the 1900 municipality of 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 fixed effects 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:

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

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 $v$ in terrain with a slope of 4or more in municipality $m$. Next, for each river class we multiply

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[20] Because of the ambiguous status of farmers, we do not consider transitions from unskilled worker to farmer as occupation upgrading; see 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.

[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, 600-750.

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 hydro potential by the size of the municipality to obtain a 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 hydropower in 1900 and those that were constructing plants at that time. As shown in Table 3, the instrument (per thousand) has no

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

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

significant effect on labor force size or workers in different sectors. These results strengthen the claim that the exclusion restriction holds.

### Table 2: First stage results, hydropower production and potential

| | Municipality sample | | Linked samples | |
|---|---|---|---|---|
| | | | Linked workers | Linked father-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 fixed effects | Y | N | Y | Y |
| Region fixed effects | N | Y | N | N |
| Adjusted R-squared | 0.15 | 0.28 | 0.15 | 0.15 |
| N | 1820 | 1820 | 30824 | 10542 |
| First stage F-value | 10,23 | 10,84 | 17,05 | 12,21 |

Data from Norwegian censuses of 1891, 1900, 1910 and 1920. Columns (1)-(2) display first stage results for the municipality regressions, while columns (3)-(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 fixed effects. In columns (3) and (4) 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.

### 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-squared | 0,46 | 0,21 | 0,16 | 0,14 |
| N | 449 | 449 | 449 | 449 |

Data: Norwegian censuses from 1891 and 1900. Dependent variables: natural logarithm of the labor force size (inhabitants 15 years and older), 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 fixed effects, 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

## 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 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 towards 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 fixed effects (FE), and FE with IV estimation.

First, we observe that according to the fixed effects and OLS models, municipalities where hydropower technology was implemented experience labor force expansion. These models show effect sizes of 39 and 14 per cent, respectively. The effect size in the fixed effect 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 fixed effects 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 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 to a fixed effects 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 are 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 4: Hydropower production, labor force size and industry composition**

| | ln(labor force size) | | | Percentage of workers in manufacturing | | |
|---|---|---|---|---|---|---|
| | OLS | FE | FE + IV | OLS | FE | FE + IV |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| 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 | N | Y | Y | N | Y | Y |
| First-stage F-statistic | - | - | 10,84 | - | - | 10,84 |
| Adjusted R-squared | 0,33 | 0,97 | - | 0,32 | 0,74 | - |
| N | 1820 | 1820 | 1820 | 1820 | 1820 | 1820 |

| | Percentage of workers in services | | | Percentage of workers in primary sector | | |
|---|---|---|---|---|---|---|
| | OLS | FE | FE + IV | OLS | FE | FE + IV |
| | (7) | (8) | (9) | (10) | (11) | (12) |
| 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 | N | Y | Y | N | Y | Y |
| First-stage F-statistic | - | - | 10,84 | - | - | 10,84 |
| Adj. R-squared | 0,37 | 0,67 | - | 0,41 | 0,77 | - |
| N | 1820 | 1820 | 1820 | 1820 | 1820 | 1820 |

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 0.4-0.7 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) suggest an increase of one 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]

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[24] We can make numerical examples using the lowest and highest category of river flow in rivers of sufficient slope. For average municipality size (654 square kilometers), an extra 65,400 meters of low-flow river (10 cubic meters per second) or an extra 872 meters of high-flow river (750 meters per second) 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.

**Table 5: Reduced form results. Relationship between natural hydropower potential, labor force size and sector employment shares**

|  | Ln(labor force) | Percentage of workers in |  |  |
|---|---|---|---|---|
|  |  | 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-Square | 0,96 | 0,74 | 0,67 | 0,76 |
| N | 1820 | 1820 | 1820 | 1820 |

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

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 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.

## Occupational mobility in hydropower municipalities

### Upward occupational mobility over careers and generations

The previous section shows how the adoption of hydropower technology in early 20th 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

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[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.

technology breakthrough, adoption of these techniques, and the concomitant industrialization process.

### Table 6: Upward mobility for unskilled workers in hydropower municipalities. Baseline and sensitivity of results

| | Baseline | | Slope and precipitation | | Pre-trend in mobility | | 1910 municipality | |
|---|---|---|---|---|---|---|---|---|
| | OLS (1) | IV (2) | OLS (3) | IV (4) | OLS (5) | IV (6) | OLS (7) | IV (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-squared | 0,04 | | 0,04 | | 0,04 | | 0,05 | |
| N | 30824 | 30824 | 30824 | 30824 | 28996 | 28996 | 30824 | 30824 |
| *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-Square | 0,06 | | 0,06 | | 0,07 | | 0,07 | |
| N | 10542 | 10542 | 10542 | 10542 | 10149 | 10149 | 10542 | 10542 |

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]

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[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.

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 instrumental variable 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 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 the sons display upward occupation mobility relative to father's occupation. We expect intergenerational mobility to be less restricted by the timing of treatment and, consequently, we expect the coefficients to be higher. As can be seen from 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 per cent), 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 U.S., 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)-(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 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. 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 attenuate 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

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[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.

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 an upper and a lower bound for the impact of hydropower production on upward mobility.

**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-Square | 0,09 | 0,11 |
| N | 30824 | 10542 |

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.

## 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. We restrict the sample to municipalities with positive values of produced power in Table 8. 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 by 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]

### Table 8: Upward occupational mobility for the unskilled groups with different treatment intensity

| | Treatment intensity in megawatts | | | |
|---|---|---|---|---|
| | MW | MW/km2 | MW/population in 1900 | MW/population density |
| | (1) | (2) | (3) | (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-squared | 0,03 | 0,02 | 0,03 | 0,03 |
| N | 1217 | 1217 | 1217 | 1217 |
| *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-squared | 0,02 | 0,01 | 0,03 | 0,02 |
| N | 457 | 457 | 457 | 457 |

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: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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

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[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.

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.

**Table 9: Timing of hydropower adoption and the likelihood of upward mobility**

| Plant opening | 1900-1905<br>(1) | 1906-1909<br>(2) | 1910-1912<br>(3) |
|---|---|---|---|
| *Panel A: unskilled manual workers, linked worker sample* | | | |
| Hydropower production | 0.06*** | 0.05** | 0.05*** |
| | (0.02) | (0.02) | (0.02) |
| Adjusted R-squared | 0,04 | 0,03 | 0,04 |
| N | 30051 | 30362 | 29589 |
| *Panel B: sons of unskilled manual workers, father-son sample* | | | |
| Hydropower production | 0.16*** | 0,08 | 0.10*** |
| | (0.05) | (0.06) | (0.03) |
| Adjusted R-squared | 0,06 | 0,06 | 0,06 |
| N | 10252 | 10371 | 10081 |

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.

In columns (1)-(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 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 20th 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 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 the 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 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 who 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 OnlineAppendix), 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

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[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.

[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.

differences across the skill distribution in response to new technology, we do not find any decisive evidence that some groups are systematically left behind.

### 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 1891 and 1900* | | | | | |
| Mean | -9,38 | 13,41 | -3,4 | -0,32 | -0,32 |
| (std. dev.) | (7.93) | (9.29) | (4.42) | (1.35) | (3.87) |
| Hydropower | 4.11*** | -6.50*** | 1,02 | -0,93 | 2.30** |
| | (1.04) | (1.82) | (1.11) | (0.67) | (1.01) |
| Adjusted R-squared | 0,34 | 0,34 | 0,21 | 0,03 | 0,12 |
| 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. Means and standard deviation for occupation shares in 1900 and change in occupation shares between 1891 and 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 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-squared | 0,04 | 0,02 | 0,01 | 0,01 |
| N | 17297 | 14152 | 11460 | 1622 |
| *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-squared | 0,15 | 0,05 | 0,03 | 0,03 |
| N | 2404 | 8243 | 3648 | 463 |

Data from Norwegian censuses of 1900 and 1910. Panel A displays results from the linked worker sample, while Panel B shows results from the linked father-son sample. Dependent variables: upward mobility indicators for manual workers in 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.

## 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 suggest 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 U.S. 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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