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4 March 2025

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Abstract:

Electrification influences economic choices, not least by allowing households to replace labour with capital and to enhance domestic labour productivity. We test whether newly electrified households invested more in children's human capital formation, proxied by secondary school enrolments, under Ireland's Rural Electrification Scheme (1947-1966). IV panel regressions examine whether electrification led to higher per capita participation in secondary education. Using a terrain ruggedness instrument, we find large and statistically significant positive effects of electrification on secondary school participation for boys. Results for girls or those using a distance to transmission instrument are not robust to corrections for spatial confounding.

Keywords: Rural electrification, secondary school, human capital, Ireland

JEL codes: I29, N34, O15.

Acknowledgements:

We are grateful to the ESB Archives for access to detailed spatiotemporal data on the Rural Electrification programme in Ireland. Helpful comments were received from participants at the 2023 Economic and Social History Society of Ireland annual conference and several 2024 events: the Irish Quantitative History Workshop, the Irish Economic Association Conference and the Economic History Association Conference in Sacramento, CA, with particular thanks to Daniela Vidart and Ann Carlos. MG acknowledges funding from the Economic History Association and the Centre for Economics Policy and History, funded under the North-South Research Programme of the Higher Education Authority of Ireland, via the Government of Ireland's Shared Island Initiative. The usual disclaimer applies.

Introduction

Electricity is credited with revolutionizing economies and societies. The literature on electrification programmes identifies positive impacts ranging from structural transformation to increased female labour force participation, but there are also cases in which substantial investments did not reap the expected rewards (Kitchens 2014, Kline and Moretti 2014, Lee, Miguel and Wolfram 2020a, Lee, Miguel and Wolfram 2020b, Burlig and Preonas 2016). Policymakers often hope that electrification will bring a range of benefits, including better education outcomes. This paper asks whether electrification supported human capital formation in rural areas in 1940s-1960s Ireland.

Between 1947 and 1966, Ireland's Rural Electrification Scheme (RES) provided residential electricity supply to about three quarters of rural dwellings for the first time (Shiel 1984). Subsidised by the government and delivered through the state-owned Electricity Supply Board (ESB), the programme was intended to provide a range of social and economic benefits. In this paper we focus on one such benefit: supporting formation of human capital. Indeed, it was hoped that electricity should bring into the lives of rural dwellers "a light which will light up their minds as well as their homes", as described by a politician of the day, James Larkin Junior (Shiel 1984). In the present paper, secondary school participation is taken as a proxy for human capital formation. We ask:

1. Did electrification of rural areas lead to higher enrolments in secondary schools during the 1947-1966 period?
2. Was the effect different for girls' and boys' enrolments?

There are several reasons to think that rural electrification might have had positive effects on enrolments. First, electric lighting provides superior lighting allowing householders to more easily and flexibly carry out domestic activities, some of which were likely complementary to investment of time and resources in human capital formation for children. Second, electrification offered opportunities to substitute capital for labour in household production, via electric irons and water pumps among others, and freed-up time may have been devoted to developing additional human capital. A third source of benefits arose from increased productivity for farms and small rural enterprises, for example through electric motors for shearing, pumping or refrigeration. Such applications of electricity tended to be adopted later than many domestic appliances, meaning that this channel likely had a more gradual effect on productivity and time use in rural households than the other two channels.

The first contribution of this research is a novel dataset that links newly digitised data from multiple sources including maps of the electrification project from the ESB archives, school-level secondary school enrolments and census small area population statistics. The order in which areas received electricity was based on the cost of connection to the pre-existing grid and the expected revenue from the area from households taking up service. We address endogeneity concerns around the order of electrification with an instrumental variable strategy.

The paper also contributes to two main strands of literature. First, we add to a growing body of economic history literature that considers the impact of the historic roll-out of electrification on a broad range of economic and non-economic outcomes.

The past research closest to ours concerns the intersection of human capital and electrification. Vidart (2024a) explores the impact of electrification in the US context on female labour force participation through increasing opportunities for skilled women. She focuses not on the rural context but on "Middle America" and on electricity's impacts on women. A second paper by Brey (2021) considers the role of hydroelectric power generation on technology adoption and innovation in Switzerland in the long run from 1850 to the present. He highlights education as an important mechanism but focuses on male education via military academy test scores, as well as the founding of new schools and local support for government expenditure on schooling. The economic history literature has yet to explore the impact of electrification on human capital formation in rural areas with careful attention to differential impacts for both boys and girls. This may be particularly relevant to contexts where electricity remains inaccessible today, and gender inequalities in educational participation and attainment persist.

Much of the economic history work on effects of electrification focuses on the United States. Kitchens and Fishback (2015) explore the impact of electrification in the 1930s on farm output, productivity and land values, finding positive impacts. Several studies have tried to explore both short and long-run economic effects of rural electrification, for example Lewis and Severnini (2020) find positive short-term effects of electrification in the 1930-1960s, but also longer-term effects using data to the year 2000. Severnini (2023) finds that dams constructed pre-1950s spurred short run local growth and long-run growth in population and employment density.

Some wider socioeconomic benefits of rural electrification have also been explored. Lewis (2018) finds a positive impact of rural electricity access on infant mortality and health in the 1930-1960s but no impact on fertility. Vidart (2024b) finds that electrification accounts for 3% of fertility decline in the US between 1910-1940, driven by young women who benefitted from labour market gains from electricity via time-saving appliances and increases in female wages.

An important dimension of the present paper is that it allows for different effects on educational participation of boys and girls. The impact of technology change on women has been explored by Greenwood *et al.* (2005) who present a theoretical framework highlighting how electricity improved productivity in the home and freed up women's time. Vidart (2024a) builds on this idea, studying the impact of electricity access on female labour force participation through "home production" and human capital channels, whereby women invested in education in order to access new forms of employment resulting from electricity in which women had comparative advantage. This paper contributes to the literature on the gender-differential effects of electrification in a context where electrification did not result in new (forms of) employment locally.

Prior research has found effects of electrification in non-rural US contexts, such as manufacturing (Fiszbein *et al*. (2024), patenting (Petralia 2020), skills and occupations (Gray 2013), and structural transformation (Gaggl *et al*. 2021), and outside the US around structural transformation and occupational mobility in Norway (Leknes and Modalsli 2020) and labour strikes in Sweden (Molinder, Karlsson and Enflo 2021). However, there is debate in the literature on how large and long-lasting such effects are, relative to the large investments needed. Studies of the Tennessee Valley Authority hydropower projects find some direct effects but limited evidence of a "Big Push" development effect that once-off large-scale investments can become self-sustaining (Kitchens 2014, Moretti and Kline 2014). Research from development economics asks similar questions, including about what complementary inputs are needed for electrification to provide significant benefits. While this paper cannot answer bigger questions around complementarities to large-scale investments, studying the Irish historical case may enhance our understanding of electrification roll-outs today in underserved rural areas where gender gaps in school participation remain a concern for policymakers.

A second literature to which the present paper makes a contribution is in development economics. Development research examines impacts of recent electrification programmes in low-income settings, across outcomes such as health (Barron and Torero, 2017), consumption and asset ownership (Burlig and Preonas 2016, Lee, Miguel and Wolfram 2020b) and productive uses of electricity (Lee, Miguel and Wolfram 2020a). Several studies consider how such outcomes intersect with gender; for example, Dinkelman (2011) finds rural electrification in South Africa increases female employment via freeing women from home production. This literature highlights the need for complementary investments to reap the full benefits of electrification (Lee, Miguel and Wolfram 2020b).

A subset of this literature focuses on education, with mixed evidence on gender differences in education resulting from electrification. Peters and Sievert (2016) study electrification and children's study time across four countries in Sub-Saharan Africa and find mixed results including positive effects, null effects, and a shift from day- to night-time study in different settings, with little evidence of gender differences. Other studies in Latin American contexts find that access to electricity is associated with greater schooling or educational attainment (Arraiz and Calero 2015, Kulkarni and Barnes 2017) with Lipscomb, Mobarak and Barham (2013) finding greater impacts on boys' enrolments than girls in Brazil. Khandker *et al.* 2014 show that rural electrification in India increases study time of boys and girls, whereas Van de Walle *et al.* (2017) see a positive link between electrification and schooling for girls in India but not boys. In Bangladesh, Khandker, Barnes and Samad (2012) find positive associations between electricity and study hours as well as completed schooling years for both boys and girls, although bigger increases in study time for boys than girls. The degree to which electrification impacts educational participation for boys and girls will likely depend on cultural norms; labour market opportunities; educational policies and supply of places; and the effects of electrification on domestic work. This paper can contribute to an understanding of how these effects may play out in a rural setting with traditional gender norms and low female labour force participation.

The present paper is structured as follows. The next sub-section discusses previous literature on rural electrification and on the determinants of secondary education participation in Ireland during this period. We then discuss the data and methods used in the paper before detailing the modelling results and discussing the findings.

Background and historical context

Electrification in Ireland

The adoption of electricity in Ireland

The Shannon Scheme (1927-1945), followed by the Rural Electrification Scheme (RES) (1946-1967) studied in this paper, took Ireland from a place where only 40,000 homes had electricity, to finally achieving full connection in the late 1970s (Shiel 1984). The RES constituted the main push in connecting rural dwellings to the electricity grid (see Online Appendix 1 for the full timeline). Prior to the RES, the Shannon Scheme had connected 240,000 urban consumers. The RES was to serve 1.75 million people, 98% of whom lived in the open countryside and only 2% in small villages. This presented financing challenges in terms of reaching isolated localities. Also, there were not nearly enough urban consumers to cross-subsidise rural ones, who were more costly due to the economies of density in constructing electricity distribution networks. Ireland's 26 counties were divided into 792 areas (we find 793 in the archive data) for the Scheme, with priority given to areas with the lowest cost of development and the highest expected take-up rates, with a minimum of one development area in each county initially (Shiel 1984). The RES offices went to considerable lengths to engage with local communities and encourage take-up and boost acceptance rates (Shiel 1984).

Accounts of life before electricity in rural Ireland highlight the drudgery of domestic and farm work (Shiel 1984). A similar, vivid picture is painted by Robert A. Caro (1992) of Hill Country, Texas, where before electric pumps or other domestic appliances, women were washing clothes by hand with water fetched by hand, heated over fires that needed constant tending. People also lacked the entertainment and information provided by radio and television and were not necessarily aware of large gaps between rural and urban living standards.

Electrification was understood to be especially beneficial for "women's work", which was often assisted by the children of the household. Much of the advertising and informational pamphlets was directed at women (for an example, see Online Appendix 2, Figure A2.1), apart from those in farmers' publications. Educational displays showing domestic appliances travelled the country, and from 1947 onward the Royal Dublin Society Spring Shows displayed appliances and uses. Voluntary organisations such as the Irish Countrywomen's Association encouraged take-up of electrical appliances and electric pumps for running water. Table A3.1 in Online Appendix 3 illustrates the trends in rates of domestic appliance ownership among rural consumers. The first electric appliances adopted by households were generally light bulbs (Weisbuch 2018), followed by the mains radio, a vast improvement to the battery-operated version. Electric irons were swiftly adopted with 68% of rural electricity consumers owning one in 1958 (ESB Time-Series Survey Data cited in Shiel 1984, p. 166), and 87% in 1979. Other devices such as television rose rapidly from low levels of 23% in 1964 to 84% in 1979. Despite the manifold benefits of running water in the house, rural "aquafication" was slower than electrification, with male household heads often neglecting to install this, if not needed for farming purposes, to the detriment of their wives (Shiel 1984).

Electrification and education in Ireland

An important and very affordable benefit of electrification was electric lighting, which was qualitatively superior to kerosene lamps and other sources that were previously used. Electrification enabled people to work, sew, play cards and read without daylight, especially important in the Irish context where there is less than eight hours daylight on the shortest days of the year. School children would be key beneficiaries of increased hours for reading and writing.[1] With more hours to spend on study, or on the mix of study and chores (home and farm work), it would be easier for rural children to keep pace with their studies. Electrification may have decreased time spent on chores which could be substituted for schoolwork. Given the gendered nature of household work there may be different effects for girls and boys. There may also have been educational improvements due to improvements in health from better sanitation and indoor air quality (Lewis 2018).

Secondary education in Ireland in the 1940s-1960s

The study period was one of expansion in the numbers of secondary school students and of schools. Between the 1946/47 and 1966/67 school years, enrolments in recognised secondary schools[2] rose by 41%, from 42,927 to 103,558 (based on analysis of annual reports of the Department of Education).

The Irish education system

The Irish education system relied heavily on religious organisations and personnel for staffing and governance. Male- and female-led Catholic orders began to open single-sex schools in the 19th century (Walsh 2016). There were no State-established secondary schools in Ireland until the opening of comprehensive schools in 1966 (at the end of the study period). Teaching staff from religious orders were central to education provision. There seems to have been a greater diversity of female religious orders than male orders and a greater number of girls' schools than boys (O'Donoghue and Harford 2016). This may be one reason why there are more girls' secondary schools than boys' in our data also.

At the beginning of the Rural Electrification Scheme in 1947, Ireland had one of the poorest economies in Europe (O'Hagan and Newman 2014), yet had a better-developed school system and higher participation rates than one would expect for its national income (Tussing 1978). This stemmed from a frugal education system with Church influence in school ownership and teaching, as well as a low-technology "arts" curriculum (Tussing 1978). Tussing contends that Ireland's schooling was developed for "moral and intellectual instruction" meaning girls' education was not neglected like in other contexts where education focused on economic returns. However, girls' education was largely about preparing for marriage via "accomplishment" subjects (O'Connor 1986). Attitudes changed over our study period, and education was increasingly seen as an engine for growth.

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[1] Although Caro (1992) notes that parents, who generally had worse eyesight than children, would potentially have benefitted more from improved lighting.

[2] Essentially all secondary schools in Ireland operated under state recognition (Tussing, 1978). This allowed them to receive capitation grants subject to administrative requirements including rules governing premises; staff numbers, conditions of employment and salaries; and curriculum (for example, Department of Education 1925.)

Secondary schooling

Secondary education consisted of a junior cycle with the Intermediate Certificate Examination, a senior cycle culminating in the Leaving Certificate Examination, or alternatively vocational education in vocational schools finishing with the Group Certificate. The minimum school leaving age during the study period was 14. Subject choice, especially in vocational education, was highly gendered, reflecting gender norms and a gender-segmented labour market.[3]In 1963/64, 73% of second-level students were in Secondary Schools and 27% in Vocational Schools.[4] The OECD's 1965 Investment in Education report estimated that about 35% of primary school leavers in 1958 left full-time education, 42% entered Secondary Schools (fee-paying) and 23% entered Vocational Schools (non-fee-paying). Of those who entered Secondary or Vocational schools, around 29% left without any qualification, 35% left with an intermediate qualification, 29% left with the final school leaving certification and only 6% would go on to university (O'Donoghue *et al.* 1965). Dropout rates after one or two years of secondary school were high, but higher for boys than for girls (who were fewer in number) (O'Donoghue and Harford 2016). To illustrate the quality of school infrastructure during the study period, in 1963, 41% of national (primary) schools did not have access to electricity and 55% did not have flush toilets.

Educational inequalities

Prior to the "Free Scheme" providing free secondary school education to all from the school year 1967/68 onward, those who got secondary education would have been primarily middle- and upper-class (Callan and Harmon 1999). Different opinions exist on the extent to which secondary school fees (and transport costs) would have burdened rural households (Denny and Harmon 2000; Fleming and Harford 2014). In 1955-1956, 31% of secondary school boys and girls were boarders (O'Donoghue and Harford 2016). There were clear distinctions between the boarding school (upper middle class), the convent day "pension/pay" school (middle/lower-middle class) or the convent "national" school (working class).

In terms of gender, boys had greater access to secondary education than girls during the study period. Clarke (2016) estimates that in 1931-1932, 59% of secondary school students were boys, but by 1961-1962 this was closer to 50:50 (based on Department of Education Annual Reports). Another feature of Irish education during the period is "secondary tops", the practice of students remaining at primary school but undertaking secondary school studies for one or two years before leaving school or taking the Intermediate Certificate examination (Delaney 2022). The main rationales were to provide some secondary education in areas without a secondary school and to assist students with difficulties affording secondary education (O'Donoghue *et al.* 1965, Annex D). This educational option was far more prevalent for girls than for boys. In 1939-1940, there were 61 secondary tops in the country (with 3,627 girls and 259 boys). In 1956-1957, there were 87 secondary tops (5,570 girls and 511 boys). In 1961-1962 there were 6,641 students in secondary tops, 94%

[3] Indeed, a marriage bar was in place during the study period which meant that any woman continuing her education and career was forced to abandon it upon marriage (Mosca and Wright 2020).
[4] Comprehensive and Community Schools fall outside our study period with the first of each opened in 1966 and 1973 respectively (Tussing 1978).

female (O'Donoghue and Harford 2016). See Online Appendix 4 for more detail on Irish education policy during the study period.

Data and methods

Unit of analysis: school catchments

Most secondary schools in Ireland during the sample period were single sex. In order to allow separate models of boys' and girls' enrolments, we constructed separate school samples for girls and for boys and assigned the students in coeducational schools to the sample of the relevant sex. Some towns in Ireland had more than one secondary school in the sample period, even after partitioning the schools by sex of the pupils. We therefore grouped secondary schools by the settlements (mostly towns and villages) in which at least one recognised secondary school was located throughout the sample period. To identify relevant area characteristics, we partitioned the country into a series of relevant local areas centred on each of these settlements, which we term "catchments". They are not strictly school catchments, since we have no data on pupil flows from homes to schools. In effect, we assumed that on average students are more likely to attend the nearest school using Euclidean distance.

Initially, we partitioned the country into a set of geographical areas nearest to the centroids of all relevant settlements by generating Voronoi diagrams around the relevant settlements, separately for boys' and girls' school samples. A few minor manual adjustments were made to these boundaries to make sure we were not assuming that pupils would cross water to get to school (for example, in the southwest of the country). See the left panel of Figure 1**Error! Reference source not found.**, which illustrates this method using girls' school catchments.

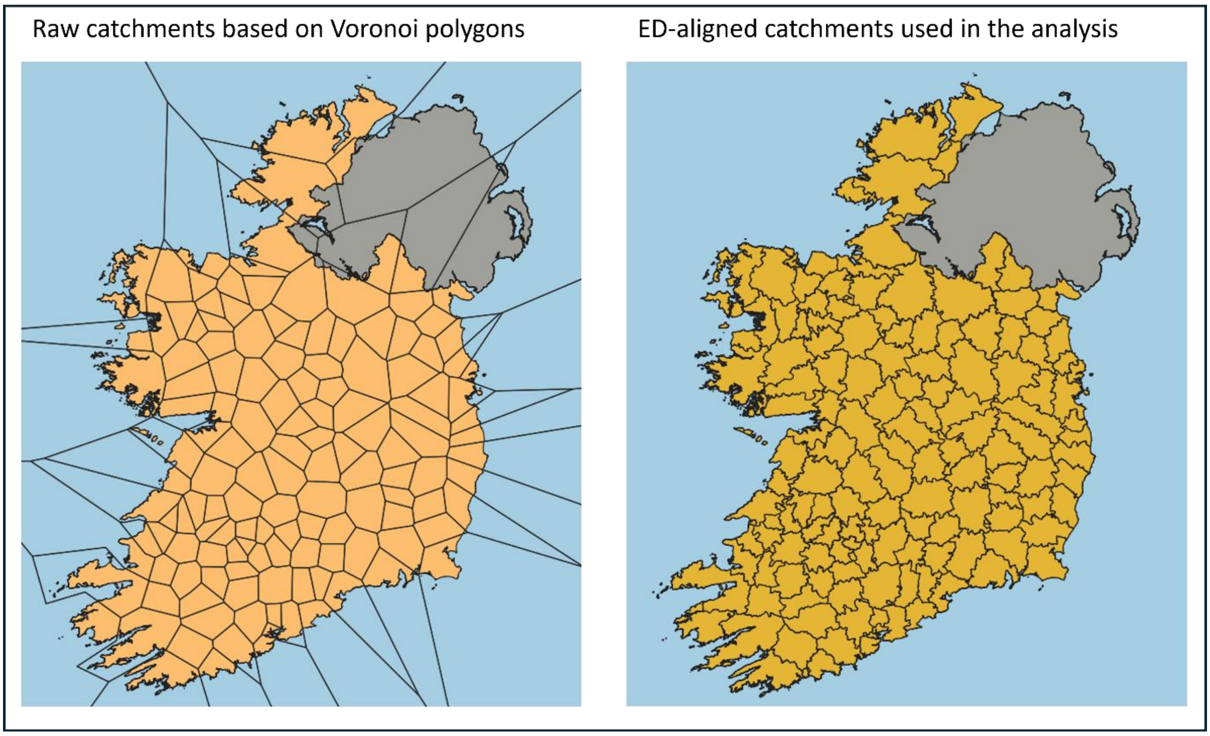

Figure 1: Illustration of how school catchment areas were constructed

To allow matching of population and other area characteristics to school catchments, we assigned each Electoral Division (the smallest available administrative boundary, referred to hereafter as "ED") to a catchment based on the location of the ED centroid. This yields a map with administrative boundaries, as illustrated in the right panel of Figure 1.

Dependent variable: secondary school enrolment intensity

We added up enrolments separately for boys and girls for each year in each catchment over time. There are considerable variations across the populations served by school catchments in Ireland, as shown in Table 1. We normalised our enrolment outcome measure by dividing secondary school enrolments for each year by an estimate of the catchment population. ED level population data and rateable values for 1946 and 1966 were obtained by digitising CSO census data for each of these years (sourced from Table 11 in each census report). We interpolated between the two census years to obtain estimates of annual population. Unfortunately, published census statistics at ED level only capture population totals for males and females, not specific age groups such as those that might be most likely to attend secondary school. We divided the catchment enrolments for boys by the number of males in each catchment and girls' enrolments by the number of females. These ratios are described as "enrolment intensities".

Higher enrolments in secondary schools can come about as a result of more children enrolling, and moving from primary school to secondary, or as a result of children who enrol being less likely to drop out, improving overall enrolment levels (extensive versus intensive margin). The enrolment intensity measure combines changes at both intensive and extensive margins.

Table 1: Sample descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Girls' school sample					
Enrolments	1,995	160	125	5	1,051
Enrolment intensity	1,995	0.0254	0.0165	0.000503	0.100
Electrification share	1,995	0.590	0.377	0.00	1.00
Terrain Ruggedness Index	1,995	4.30	2.43	1.38	13.2
Distance to transmission	1,995	3.00	4.37	0.0378	26.7
Valuation per capita	1,995	4.99	1.61	0.963	10.2
Population density	1,995	0.133	0.0837	0.0385	0.826
Boys' school sample					
Enrolments	1,680	173	150	6	761
Enrolment intensity	1,680	0.0218	0.0166	0.00103	0.159
Electrification share	1,680	0.596	0.370	0.000182	1.00
Terrain Ruggedness Index	1,680	4.49	2.52	1.15	13.7
Distance to transmission	1,680	3.11	4.62	0.0734	23.9
Valuation per capita	1,680	5.06	1.58	1.75	10.2
Population density	1,680	0.129	0.054	0.0426	0.381

The five cities in Ireland – Dublin, Cork, Limerick, Galway and Waterford – were provided with residential electricity services prior to the sample period. Since they exhibit no sample variation for the policy variable of interest, we dropped these areas from the analysis.

The development of enrolment intensities over time is illustrated in Figure 2, using the example of girls' school catchments. Most catchments experienced increases in enrolment intensity over the sample period, but the temporal pattern of increases varied considerably. It appears that no school-level enrolment statistics were published for the six years from 1953/54 to 1958/59 (see the shaded areas in Figure 2), and we have been unable to find data in the National Archives or elsewhere to allow these statistics to be reconstructed. As a result, the available sample is limited to seven years from 1946/47 and eight years up to 1965/66.

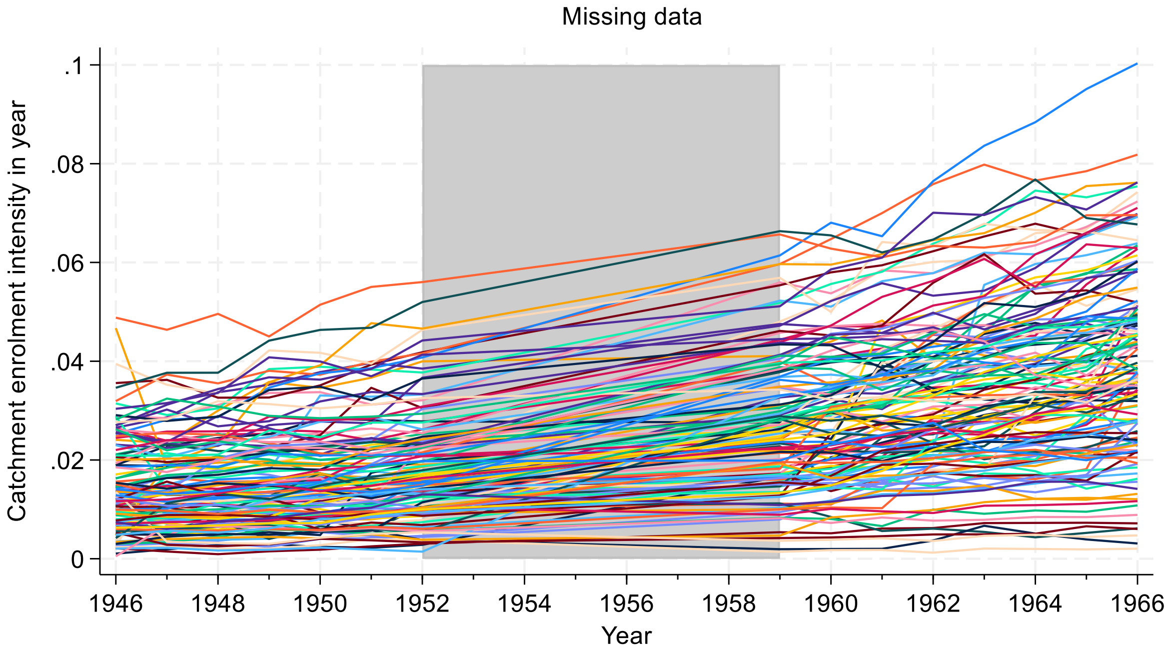

Figure 2: Enrolment trends in all girls' catchments over time. The listed years are the first in each academic year pair (for example, 1946 represents 1946/47)

Another omission in the available data on secondary enrolments is school-level data for vocational schools and secondary tops (as discussed earlier, the practice in some areas of permitting students to undertake lower secondary schooling in primary schools). These forms of education are omitted from our catchment data.

Policy variable: share of population offered electricity

The ESB Archive has published scanned maps describing the Rural Electrification Scheme area boundaries. We georeferenced these map images on to an historical Ordnance Survey map and traced the area boundaries to build up a complete map of Rural Electrification areas (n=793), linked to build dates provided by the ESB Archive for each area. This process is discussed in Online Appendix 5. We also constructed a map of the 464 areas that had electricity previously (including areas electrified in the Shannon Scheme or earlier). Since there we are not aware of maps of the Shannon Scheme area boundaries, we mapped the boundaries of these earlier electrification areas based on modern CSO settlement or townland definitions. 92 areas that were not electrified by the end of the Rural Scheme were also mapped based on the gaps in the Rural Scheme map that did not equate to Shannon Scheme areas. See Figure 3. Assuming population was spread evenly within EDs, the population of the 92 remaining areas made up less than 5% of the total population of the state in 1946. In fact, the population share was probably lower than that, because the portions of EDs least likely to be provided with electricity service were those with the lowest population density. Most of these areas were located in what Desmond Gillmore, a contemporary geographer, termed the "Western Small Farm Fringe" agricultural region (Gillmore 1965).

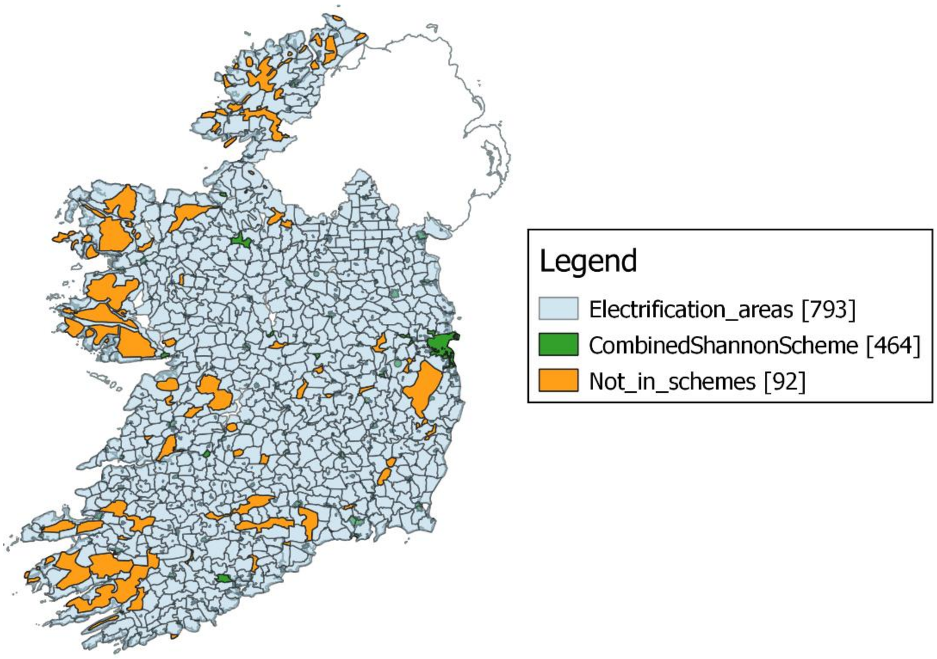

Figure 3: Boundaries of areas within Ireland classified by electrification status

Using maps of areas covered by the Rural Electrification Scheme and earlier electrification projects, we estimate the share of population in each catchment that was offered electricity each year during the sample period. We hypothesise that this metric ("electrification share") will have a positive relationship with school enrolment intensities. It is positively trended everywhere, but the timing of electrification varied across areas. Descriptive statistics are included in Table 1.

Instrumental variables

Electrification share should be endogenous in a model of enrolment intensities. Administrative records indicate that a two-part test was used to determining the timing of infrastructure delivery for rural electrification in this period (Shiel 1984). One part considered the expected cost of installation, which likely depended upon local topography and the distance to existing network elements. The second part was based on data gathered from areas in advance of infrastructure development about how many households were likely to take up electricity service. The expected number of electricity adopters was affected by the socioeconomic characteristics of areas, with households on the lowest incomes, older households, and those with more traditional views around social and technological change often being more reluctant to express interest in taking up electricity (Shiel 1984). Socioeconomic factors seem likely also have a direct effect on households' propensities to send children to recognised secondary schools.

To address the endogeneity arising from the influence of incomes on both rollout of electrification and enrolments, we consider two possible instruments for the relative costs of extending an electricity distribution network into different geographical areas. In our sample period rural electricity distribution was provided by single phase 10kV lines carried along poles, with pole-mounted distribution transformers used to step down the voltage to 220V for groups of 1-10 premises (Duffy 2011). Thus, the cost of construction for a given piece of distribution grid would have been driven by the quantity of network components (kilometres of wire, numbers of poles and transformers) and the civil works needed to put them in place. Distribution grids were linked to power generation sources by a long distance high and medium voltage transmission grid. We focus on two attributes of areas that should have affected infrastructure costs:

1. The topography of the proposed grid extension, proxied by *terrain ruggedness*. The intuition behind this instrument is that a hilly area should require more infrastructure to serve a given population than a perfectly flat area. The average distance between distribution nodes (and hence the cost of components and works) must be larger if the average terrain height difference between nodes is greater than zero, assuming nodes are distributed identically in flat and hilly areas. Of course, rugged and flat areas may also exhibit differences in the spatial distribution of premises, so whether ruggedness is a strong predictor of costs is an empirical question. The metric we use is the Terrain Ruggedness Index ("TRI"), introduced by Riley, DeGloria and Elliot 1999. The TRI is calculated using the European Digital Elevation Model, version 1.1 at 25m resolution, provided by the Copernicus Land Monitoring Service; see Figure 4.
2. The *distance of the proposed rural grid extension from the pre-existing transmission network*. Our proxy for this instrument is the distance from the boundary of each rural electrification area to the nearest 10Kv transformer station on the transmission grid as of 1938. Having to build a longer connection to the transmission grid to extend service to a given piece of distribution network would straightforwardly increase the cost. A map of Ireland's transmission links and nodes in 1938 is provided in Online Appendix 6.

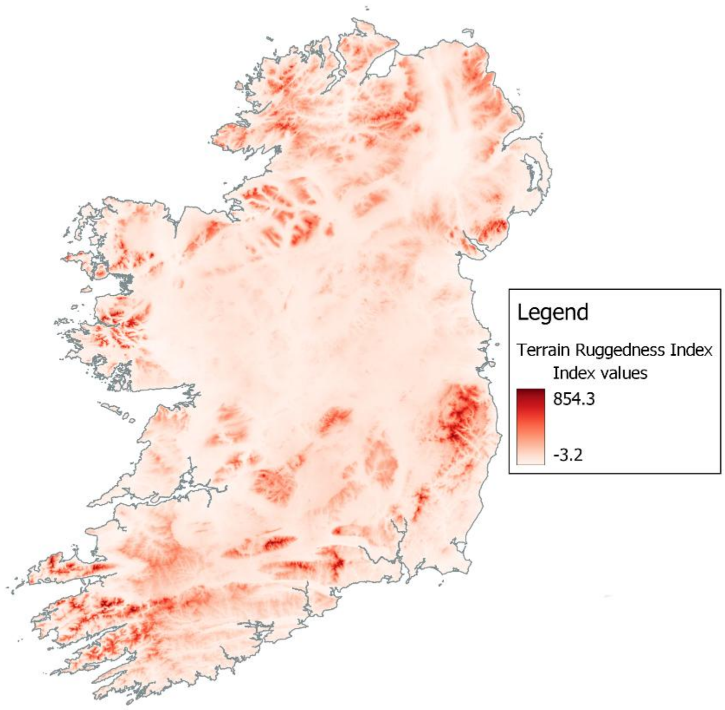

Figure 4: Terrain Ruggedness Index for Ireland, 25m grid.

We propose that interactions between each of these metrics for each catchment and the level and squared values of a time trend should be valid instruments for the electrification share in each catchment-year unit. Only interactions are included in the models, because starting values are absorbed by the catchment fixed effects included in our regressions. We run regressions with each of the proposed instruments separately because the metrics are correlated, possibly because terrain ruggedness also affected the distance of areas from the transmission grid prior to our sample period.

Terrain Ruggedness

The development literature concurs that an area's topography, particularly ruggedness, can lead to higher costs when building rural electricity grids (Slough *et al*. 2015). However, for local terrain ruggedness to be a valid instrument in this context, it must not have direct effects on the time trend in school enrolments in addition to the indirect effects we have outlined. In other words, is it possible that hilly areas experienced faster growth in secondary school enrolments than flat areas during this period for some other reason?

This is impossible to disprove, but there are some indications that such factors might not have been empirically important. For boys' school catchments, TRI and enrolment intensity levels had only a weak negative association at the end of our sample period (about 8% of the sample standard deviation), and for girls there was no significant correlation. Univariate cross-sectional regressions of enrolment intensity on TRI for boys' and girls' catchments in the start and end years yield the coefficients in Table 2 below. If there was another mechanism correlated with electrification that actually explained some of the trends in school enrolments, it does not seem to have led to a large or persistent deviation in enrolment levels between hilly and flat places.

Table 2: Coefficient on TRI from univariate regressions on enrolment intensity at start and end of sample period

	Girls' school catchments		Boys' school catchments	
	Coef.	P-value	Coef.	P-value
1946/47	-0.000479	0.115	-0.0007228	0.066
1966/67	-0.000833	0.208	-0.0013139	0.034

We have not been able to identify any contemporaneous changes in factors other than electrification that differed systematically between rugged and flat areas that might have been expected to positively influence local secondary school enrolment trends, such as improvements in school transport, reductions in school fees, changes in farming patterns or shifts in employment opportunities. No grants were made available for transport to secondary schools during the sample period (O'Donoghue *et al*. 1965). As noted earlier, the national scheme for free fees (and school transport) was also implemented later. While soil types in rugged areas were (and are still) systematically different from those in flat areas, likely affecting agricultural productivity, this did not change during the period of our study. Unfortunately, there are no spatially granular data on changes in employment patterns in Ireland during this period.

Distance to the pre-existing electricity transmission grid

Distance to the nearest node on the transmission grid has previously been used as an instrument for take-up of rural electrification in a model of educational activity (Aguirre 2017). It is not obvious why distance from the high and medium voltage transmission grid *per se* should have a direct effect on time trends in educational participation, though of course we cannot rule out omitted factors affecting both variables as discussed for TRI above.

Other explanatory variables

All models are estimated using catchment fixed effects, allowing for unobserved non time varying heterogeneity in the determinants of enrolment intensity across catchments. A time trend is included to allow for any general increase in enrolments across the country as incomes, state support for education and preferences changed over time. We include two time-varying controls that might be expected to be associated with enrolments (their descriptive statistics are included in Table 1):

- Rateable valuation per capita, a proxy for wealth using a population-weighted average across EDs from annually interpolated census statistics (see Figure 5); and
- Population density, similarly interpolated between census years.

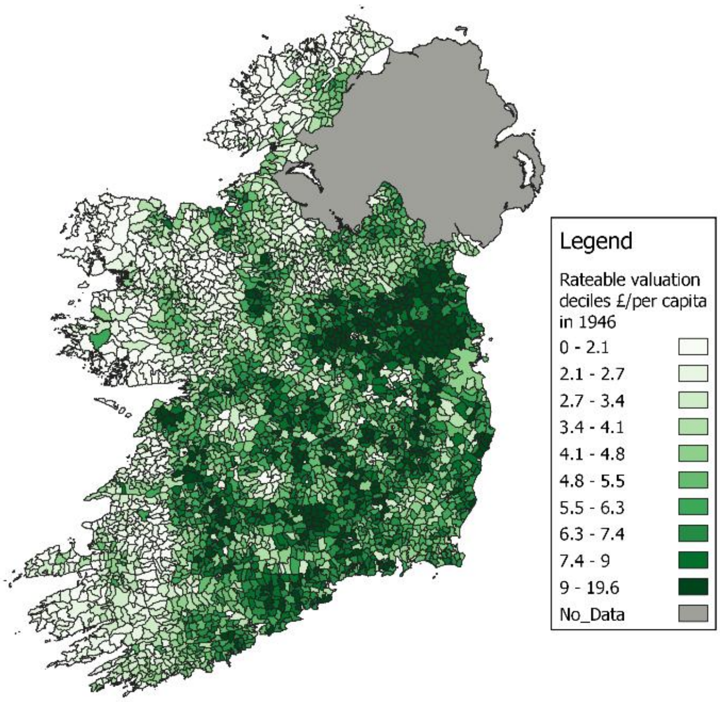

Figure 5: Electoral division[5] average rateable valuation per capita in Ireland, 1946.

Methodology

In a standard human capital theory setting, education serves as an investment that can increase lifetime earnings (Becker 1975; Mincer 1993). Households choosing how much education to undertake maximise the expected discounted value of future benefits of educational investments minus a range of direct costs including school fees and other education-related costs such as suitable clothing, educational materials and transport to

[5] Dublin electoral divisions consolidated.

school. There are also important indirect costs associated with the opportunity cost of displaced productive activities or (important in the current setting) unpaid domestic work. Access to credit or current household wealth, particularly for credit-constrained households, can also play a role in determining the amount of education that is undertaken. There is considerable household-level heterogeneity in many factors driving these costs and benefits, and both the quality of available information and the extent of parameter uncertainty may vary across households.

To explore how electrification changed households' decisions about investments in human capital, we estimate regression models to explain average enrolment intensity at catchment-year level. We can explicitly allow for some sources of heterogeneity in the models, particularly pupil gender. Gender likely affects both benefits, such as returns to education, and costs, including opportunity costs of paid labour and domestic work that are foregone. There may also be gender differences in the supply of education since most schools in Ireland at this time were single sex. As noted earlier, geographical analysis yielded different numbers and sizes of school catchments for boys and girls. We therefore estimate separate regression models for girls' and boy school catchments, so all parameters are allowed to vary by gender. Other aspects that can be explicitly modelled include non time varying sources of heterogeneity among areas (using fixed effects), average wealth (proxied by rateable value per capita) and quality of transport and other local amenities (proxied by population density).

To allow for possible endogeneity of the electrification share, we estimate panel two-stage least squares regressions. Two possible instruments are tested separately: the Terrain Ruggedness Index and the distance from the boundary of each electrification area to the nearest 10 kV node on the transmission grid in 1938. Since both of these measures are cross-sectional, each is interacted with time and time squared before being included in the first stage of each 2SLS model. We test the two possible instruments separately. The data described above yield a sample for analysis of 133 catchments for girls and 112 for boys, both balanced and covering 15 years with a six-year gap in the middle. The two stages of the model are summarised below (beta coefficients omitted for brevity):

1. $\frac{Elec_{t,a}}{Pop_{t,a}} = Time_t + Time_t^2 + [TRI_a/TDIST_a] * Time_t + [TRI_a/TDIST_a] * Time_t^2 + ln\left(\frac{Val_{t,a}}{Pop_{t,a}}\right) + ln\left(\frac{Pop_{t,a}}{Area_a}\right) + \mu1_a + \varepsilon1$

2. $\frac{Enrol_{t,a}^{[girls\|boys]}}{Pop_{t,a}^{[females\|males]}} = \frac{\widehat{Elec_{t,a}}}{Pop_{t,a}} + Time_t + Time_t^2 + ln\left(\frac{Val_{t,a}}{Pop_{t,a}}\right) + ln\left(\frac{Pop_{t,a}}{Area_a}\right) + \mu2_a + \varepsilon2$

Elec is the population of each catchment (*a*) offered electricity, and *Pop* is its total population in each period (year *t*). *Time* is a time trend, *TRI* is the average Terrain Ruggedness Index in the catchment, *TDIST* is the distance from the boundary of each electrification area to the nearest 10 kV node on the 1938 transmission grid, *Val* is a population-weighted average of the rateable valuation across EDs in the catchment. *Enrol* is the number of enrolments of each sex in the catchment during *t*. *Area* is the geographical area of each catchment, the μ terms are catchment fixed effects and ε denotes error terms.

We attempt further robustness tests to allow for the spatial character of the data. Estimating our regressions with fixed effects absorbs non time varying factors including those that are spatially dependent. However, it is still possible that there is spatial dependence among the factors that do vary over time. If unobserved spatially patterned factors were to be correlated with time varying explanatory variables, this could lead to omitted variable bias. A growing literature in biostatistics refers to this problem as “spatial confounding”. One approach to addressing this problem is to include spatial smooths as regressors. However, spatial smoothing can lead to bias in coefficients (Dupont et al. 2022). In an effort to adjust for such effects, we adapt the geoadditive structural equations model (gSEM) model introduced by Thadden and Kneib 2018 and discussed in a wider context by Dupont *et al*. 2022.

To work in a setting with instrumental variables and fixed effects, we make some adjustments to the original gSEM approach. We use generalised additive models to estimate univariate regressions relating each of our variables (dependent and explanatory) to smoothed representations of their spatial patterns. Two types of smoothing are used, both with k=40: 1) a spatial spline representation of the centroids of school catchments and 2) a Markov Random Field (MRF) smooth of the catchment polygons. These regressions capture the spatial structure in each variable in different ways: a spatial spline treats space as continuous, while the MRF smooth treats space as a set of areal units that may or may not be adjacent to one another. We then use the residuals from each of these regressions, in effect the non-spatial components, in place of the original variables in the two-stage least squares models described above. In essence, we re-estimate the models after spatial dependence has been removed.

A second simpler set of robustness tests for spatial dependence are applied by re-estimating the base 2SLS fixed effects models for both sexes and instruments while allowing separately for spatial autocorrelation and autoregression (Anselin 1988). Inverse distance and contiguity spatial weights matrices are both tested.

Software: QGIS v.3.22 was used for GIS analysis; Stata v.18 and R v.4.3.1 were used for econometrics and other quantitative analysis.

Results

Separate results are shown for models of girls’ and boy’s catchments and for two potential instruments: terrain ruggedness and distance to the nearest 10Kv transformer in the 1938 transmission grid. Table 3 shows results for the second stage models explaining secondary school enrolment intensities as a function of predicted electrification shares from the first stage, fixed effects and other explanatory variables.

Table 3: 2SLS regression results for enrolment intensity models, second stage, separate models for girls' and boys' school catchments and for two potential instruments

Variables	Girls				Boys			
	Instrument: Ruggedness		Instrument: Dist. to transmission		Instrument: Ruggedness		Instrument: Dist. to transmission	
(DV=enrolment intensity)	Coef.	Robust SE	Coef.	Robust SE	Coef.	Robust SE	Coef.	Robust SE
Elec. share	0.0125	0.00493**	0.0477	0.0155***	0.0211	0.00369***	0.0313	0.00900***
Time	-0.000760	0.000375**	-0.00323	0.00110***	-0.00122	0.000271***	-0.00193	0.000626***
$Time^2$	4.86e-05	7.30e-06***	8.50e-05	1.70e-05***	3.91e-05	5.44e-06***	0.0000491	0.0000096***
Ln(Val. per cap.)	0.0411	0.00874***	0.0671	0.0178***	0.0639	0.00830***	0.0720	0.0111***
Ln(Pop. dens.)	0.0190	0.00917**	0.0622	0.0233***	0.0784	0.00904***	0.0919	0.0142***
Obs.	1,995		1,995		1,680		1,680	
R^2	0.689		0.437		0.585		0.484	
No. catchments	133		133		112		112	
No. years	15		15		15		15	

*** p<0.01, ** p<0.05, * p<0.1

Table 4: 2SLS regression results for enrolment intensity models, first stage (Electrification share), separate models for girls' and boys' school catchments and for two potential instruments

Variables (DV = electrification share)	Girls				Boys			
	Instrument: Ruggedness		Instrument: Dist. to transmission		Instrument: Ruggedness		Instrument: Dist. to transmission	
	Coef.	Robust SE	Coef.	Robust SE	Coef.	Robust SE	Coef.	Robust SE
Instrument*Time	-0.00459	0.000769***	-0.00158	0.000415***	-0.00459	0.000762***	-0.00158	0.000431***
$Instrument*Time^2$	0.000122	0.0000347***	0.0000586	0.0000186***	0.000128	0.000034***	0.0000549	0.0000194***
Time	0.0868	0.00424***	0.0737	0.00273***	0.0848	0.00425***	0.0713	0.00285***
Time2	-0.00156	0.000191***	-0.00121	0.000116***	-0.00154	0.000192***	-0.00114	0.000121***
Ln(Val. per cap.)	-0.421	0.127***	-0.617	0.153***	-0.401	0.152***	-0.614	0.175***
Ln(Pop. dens.)	-1.13	0.106***	-1.216	0.127***	-1.23	0.129***	-1.297	0.147***
F-test of excluded instruments	F(2,1856) = 101 [p=0.000]		F(2,1856) = 12.5 [p=0.000]		F(2,1562) = 80.4 [p=0.000]		F(2,1856) = 14.5 [p=0.000]	
Underidentification: Kleibergen-Paap rk LM	$\chi^2(2)$=112 [p=0.000]		χ2(2)=15.0 [p=0.000]		$\chi^2(2)$=91.0 [p=0.000]		χ2(2)=18.1 [p=0.000]	
Weak identification: Cragg-Donald	F=81.3		F=8.96		F=67.9		F=11.5	
Overidentification: Hansen J	$\chi^2(1)$=0.589 [p=0.443]		χ2(1)=2.07 [p=0.150]		$\chi^2(1)$=0.069 [p=0.792]		χ2(1)=5.01 [p=0.025]	

*** p<0.01, ** p<0.05, * p<0.1

The model of boys' school catchments indicates that electrification had large, positive and highly significant effects on enrolment intensity (>1 standard deviation in the dependent variable). The model of girls' school catchments indicates similar scales of impact but less precisely measured effects.

Table 4 provides the first stage results from the models shown in Table 3. Both instruments are highly significant with the expected negative coefficient on the time trend and a smaller positive coefficient on time squared. Diagnostics provided for the ruggedness instruments in this table indicate strongly that that the instruments are not under-identified or weak, and the over-identification test do not reject the null hypothesis that the instruments are valid. We find strong evidence in these models that the electrification share variable is endogenous. However, the diagnostic results and goodness of fit are considerably stronger for the ruggedness instruments than for distance to the transmission network (although the latter passes most standard tests). The use of 2SLS regression has significant effects on the signs, level and significance of the electrification share coefficients; see Table A7.1 in Online Appendix 7 for comparable panel fixed effects OLS results.

Turning to the results of robustness tests to address possible spatial confounding, Table 5 shows the electrification intensity coefficients based on estimation after spatial patterning is removed. See Online Appendix 8 for the full regression results. The coefficients for boys' catchments are qualitatively similar to the unadjusted 2SLS results when using the ruggedness instrument. In contrast, results for girls' catchments show no significant effect when the ruggedness instrument is used after removing spatial patterning from the variables.

Table 5: Second stage IV electrification intensity coefficients from models with all variables replaced by residuals from spatial spline and MRF regressions

Spatial spline smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
Ruggedness instrument				
Electrification intensity, predicted	0.000523	0.00693	0.0250	0.00646***
Transmission distance instrument				
Electrification intensity, predicted	-0.0757	0.0472	0.0105	0.0128

MRF smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
Ruggedness instrument				
Electrification intensity	0.00785	0.00995	0.0239	0.00539***
Transmission distance instrument				
Electrification intensity	0.0826	0.0356**	0.0401	0.00804***

The transmission distance instrument does not seem to be robust to the gSEM adjustment. The electrification intensity coefficients vary widely. The reason for this is apparent from Table 6, which shows the key coefficients from the first stage of the 2SLS regressions. When gSEM adjusted variables are used, the interaction terms between transmission distance and time lose all significance in the first stage regressions explaining electrification share over time. Transmission distance ceases to be a valid instrument after this adjustment.

Table 6: First stage IV instrument coefficients with all variables replaced by residuals from spatial spline and MRF regressions

Spatial spline smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
Ruggedness instrument				
TRI*Time	-0.0128	0.00244***	-0.0133	0.00267***
TRI*Time^2	0.000482	0.00011***	0.0005	0.000119***
Transmission distance instrument				
Transmission distance*Time	-0.00032	0.00139	-0.00171	0.00191
Transmission distance *Time^2	0.0000252	0.0000605	0.0000436	0.0000828

MRF smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
Ruggedness instrument				
TRI*Time	-0.00892	0.00217***	-0.0109	0.00225***
TRI*Time^2	0.000344	0.0000989***	0.000389	0.000101***
Transmission distance instrument				
Transmission distance*Time	-0.00117	0.00107	-0.00181	0.00154
Transmission distance *Time^2	0.0000473	0.0000461	0.0000335	0.0000662

As a further robustness test, we re-estimated the base models using traditional spatial econometrics adjustments for spatial autocorrelation and autoregression with both inverse distance and contiguity matrices (see Online Appendix 9 for the electrification intensity coefficients). As in the case of the gSEM robustness test, transmission distance does not appear to be a valid instrument when spatial lags are included. The results for boys' school catchments are not qualitatively different from the base non-spatial models when we allow for these forms of spatial dependence and use the ruggedness instrument. For girls' school catchments, the results suggest a lack of robustness: both signs and significance vary considerably as the specification changes. In particular, we find evidence of significant positive spatial lags in the model of girls' school catchments, with λ=0.95 [p=0.000] using an inverse distance weights matrix and 0.23 [p=0.000] using a contiguity matrix. Spatial lags are smaller in the boys' school catchment models; the corresponding figures are λ=0.47 [p=0.000] using an inverse distance weights matrix and 0.17 [p=0.005] using a contiguity matrix.

Discussion

We find a robust, highly significant, positive, effect of the electrification share on enrolment intensity in boys' school catchments during the sample period. The estimated effect is large: over 1 standard deviation in the dependent variable. It is also robust to adjustment for spatial confounding, provided we accept terrain ruggedness as a valid instrument. This result is consistent with the hypothesis that electrification accelerated the formation of human capital; indeed, the effect had a large role to play for boys in Ireland during this period.

Effect sizes for the electrification share on enrolment intensity in girls' school catchments vary more across models and these coefficients are less precisely measured. This is surprising, because the number of girls catchments is somewhat larger than boys (implying that girls' catchments are geographically smaller on average), perhaps reflecting a difference in parents' willingness for children to commute long distances to school that depended partly upon the child's gender. The greater heterogeneity in effects across models of girls' catchments compared to boys seems to depend upon something other than differences in statistical power. An adjustment for spatial confounding also yields insignificant coefficients on electrification for girls' catchments, even using the ruggedness instrument. Diagnostic tests reported in Table A8.1 in Online Appendix 8 and Table A9.1 in Online Appendix 9 suggest that there was more spatial structure in girls' enrolments than in boys'. Removing spatial dependence from the girls' data also lowers the magnitude and eliminates significance of from the electrification intensity coefficient. This does not happen when the boys' data are adjusted for spatial dependence.

These results beg the question as to why girls' school catchments show smaller and less robust effects of electrification on enrolments than boys' school catchments. The characteristics of electric appliances adopted earliest by households in Ireland and the gendered nature of domestic work during this period implied we should find the opposite.

One obvious limitation of our dataset is that we were unable to find data for enrolments in recognised secondary schools for six years in the middle of our sample period. It appears that although aggregate statistics were prepared for these years by the Department of Education, the detailed data were not published or kept. This likely reduces the power of our statistical analyses, but we do not think it introduces any biases.

There seem to be at least four possible (non-exclusive) classes of possible explanations for why boys' enrolments show stronger effects in our models than those of girls:

1. Demand for girls' places did not increase as much as boys' places due to gendered differences in the role of education for families in Ireland at this time or in the outside options available to girls and boys;
2. Girls' enrolments were significantly affected, but mainly via courses not captured in our data (vocational schools or secondary tops);
3. Demand for girls' educational places might have increased, but supply constraints (for example, teacher availability) constrained actual enrolments; or
4. The apparent difference in effects by gender might not be due to differences in enrolment patterns, but an artefact of changes in underlying population trends. Our variable of interest is enrolment intensity, the ratio of enrolments to population. Perhaps the denominators changed differently by sex rather than the numerators.

Below we briefly consider each possible channel.

First, differences in the reasons for educating male and female children during this period might help explain why electrification expanded demand for boys' education and not girls'. Some parents with limited resources likely had to choose between educating boys and girls beyond primary level. To the extent that girls' secondary education was seen as a luxury in the time before secondary education was made free, incremental time or money in rural households might have been invested in extra education for boys first. Even if the stem family model[6] was never universal even in the rural west of Ireland (Seward, *et al.* 2005), many farm families were characterised by a single son inheriting the farm with the expectation of supporting older parents. Other siblings often received implicit compensation that sometimes took the form of apprenticeships or other forms of education to help them provide for themselves (Fitzpatrick, 1983). In some households, support for daughters could have taken other forms such as dowries or assistance with emigration.

Similarly, if the labour market opportunities offered to boys and girls were changing differently during this period, this could also help explain differential effects of electrification on schooling by gender. The labour market was highly segmented with even the most attractive jobs open to girls limited to clerical and secretarial roles, services, some trades such as dress design, and lower paid professions such as teaching (mostly primary school) and nursing. Given that the bulk of (semi-)skilled manual/manufacturing work was done by men, it is possible that increasing returns to skills in these sectors incentivised parents of boys to invest more of their marginal resources in education than those of girls. In better-off households, girls were more likely to have been educated to secondary level, enabling them to train for clerical work, teaching or nursing for example, but less well-off girls could have expected only "…poorly paid domestic, industrial or service employment with few expectations and virtually no chances of promotion." (Daly 1981, p.79). Secondary education would have been less useful for those entering such roles. Many girls would also have given up work upon marriage, reducing the market returns to education. While Ireland had a late average marriage age, most people still married (Daly 2006).

We noted earlier that domestic tasks in rural homes tended to be allocated by gender during this period, with boys often assisting with farm work and girls' more typically involved in housework and caring tasks. Our expectation was that productivity of domestic tasks was affected earlier and to a greater extent by electrification, due to the earlier adoption of lighting and domestic appliances compared to farming applications. However, there is no direct evidence on relative productivity effects in Ireland during the period. If electrification substituted more fully for unskilled farm labour, this could help explain why boys' enrolments were more strongly and consistently boosted than girls'.

Furthermore, there may have been differences in the labour market alternatives open to rural boys and girls of secondary school age. There is less evidence on this, but to the extent that unskilled girls in rural areas found it easier to find employment outside the home than boys did at young ages, for example in domestic service, this might have reduced the relative attractiveness of girls' secondary education. A survey by O'Donohue *et al.* (1965) showed that boys leaving secondary school before completing any qualification went disproportionately into family farm employment (36%, vs. 16% of girls), while girls were much more likely than boys to take up non-family employment (59% vs. 38%). See Online Appendix 10.

[6] The 'stem family' or 'Harvard model' of Irish rural households is characterised by a married son who takes over management of the household during his parents' lifetime to provide a smooth transition. This transfer was accompanied by an obligation to support living parents, often within the household. Other siblings were normally excluded from control and left the household, often with some form of compensation (Fitzpatrick 1983).

Turning to the second class of possible explanations, it is worth considering whether educational options we were not able to measure might have absorbed all the increase in girls' enrolments, leading us to underestimate the effects of electrification. There are no published school-level statistics for enrolments in vocational schools or secondary tops, and we have not been able to find archival material on these types of schools either. If girls' vocational education grew more than boys' during our study period, we might not see an impact of electrification on girls' education, as they would be moving from primary schooling into vocational education and not recognised secondary schools. However, vocational school enrolments are reported annually at national level. It does not appear that girls' vocational education grew faster than boys' during this study period. Indeed, while boys' enrolments in county vocational schemes grew 136% between 1940/41 and 1960/61, girls' enrolments grew by only 40%. In single sex secondary schools during the same period, girls' enrolments grew by 126% and boys' enrolments grew by 85% (based on analysis of Clarke 2016, Tables 1 and 5).

A second educational option that might have absorbed some additional demand for girls' education (not captured in our dataset) is the secondary tops, which offered intermediate secondary education in primary schools rather than in recognised secondary schools. Secondary tops were attended disproportionately by girls, so they might seem to offer a channel for a gender-based difference in the effects of electrification. However, the number of girls enrolled in secondary tops rose from 4,035 in 1946/47 to 6,645 in 1965/66 (+65%), compared to a rise from 18,355 to 49,114 in secondary schools between the same years (+168%), based on Department of Education (1948 and 1967). We cannot completely rule out this channel without more spatially disaggregated data on secondary tops, but it seems unlikely that girls' secondary top enrolments received a much stronger uplift from electrification than secondary schools when their total enrolments grew less than half as quickly over the period.

The third class of possible explanation involves supply side constraints on the number of student places in recognised secondary schools that differentially limited the expansion of enrolments in response to electrification. If boys' schools were less constrained than girls' schools, this could help explain the observed result. However, Figure 2 showed broad-based expansion in enrolments over time for both sexes. This seems contrary to the idea that there was a binding supply-side constraint on enrolments in many girls' schools.

Finally, we might ask whether area populations changed differently for males and females across areas with earlier or later rural electrification. For this channel to understate the enrolment effects of electrification on girls relative to boys, the total female population would have had to rise relative to the male population as catchments were electrified (inflating the denominator in girls' enrolment intensity and thus reducing the measured effect). We know there was significant population change due to internal and external migration during the period, which is a key reason for focusing the analysis on enrolment intensity rather than enrolments *per se*. However, when we compare the set of areas with above and below median average level of electrification over the period, there was little difference between how male and female populations changed. See Figure 6. Both sexes experienced less population loss in areas where electrification happened earlier, but the pattern is remarkably similar across the sexes. It seems unlikely that this channel can explain the gender differences in our results.

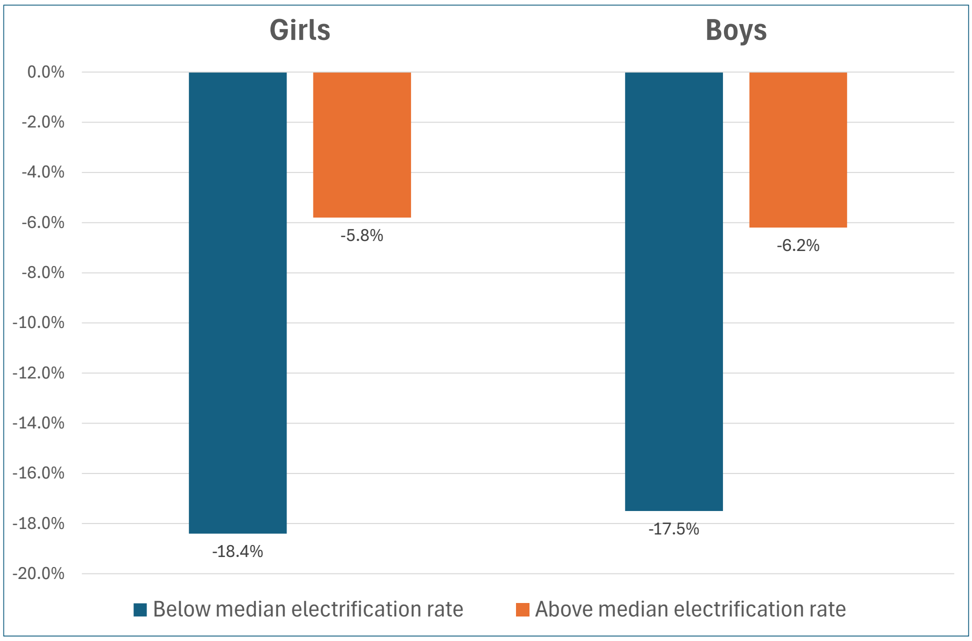

Figure 6: Average percentage change in catchment populations between 1946 and 1966, distinguishing between catchments with above and below median rates of electrification during the sample period.

Conclusion

A broad body of literature shows how electrification influences economic choices for individuals, households and firms, with important implications for economic and social change. This paper contributes to the economic history literature by asking whether the electrification of rural Ireland led to increased secondary school enrolments, and whether this effect differs for boys and for girls. Boys' secondary school enrolments in rural areas of Ireland were significantly and sizeably boosted by electrification. We find little robust evidence of a corresponding effect on girls' enrolments. While data availability limits our examination of the mechanisms, the most plausible channel for the differences we observe by sex is that the cultural and economic factors determining human capital accumulation choices were quite different for girls and boys in Ireland at this time. This chimes with the development economic literature that finds differential effects of rural electrification for boys and girls across various settings and adds to the extant literature on the effects of improving electrification access in rural areas, especially where policymakers are concerned about gender inequalities in education outcomes and beyond.

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Appendices

Appendix 1 - Timeline of electrification in Ireland (based on Shiel (1984))

Shannon Scheme:

13 August 1925: contract for Shannon Scheme signed between the Irish government and Siemens Schuckert (£5.2 million, 3.5 years time for completion).

11 Aug 1927: ESB established via Electricity (Supply) Act 1927.

22 July 1929: official opening of the Shannon Scheme.

Oct 1929: first current commenced flowing.

April 1936: a schedule of rates of charge for supply to villages of not more than 50 population and isolated consumers in rural areas was produced.

May 1939: Seán Lemass (Minister for Industry and Commerce) requested ESB to prepare plans to supply rural areas with electricity and to make proposals regarding financing and other aspects of implementation.

Sep 1939: Outbreak of WWII: 170,000 consumers had been connected and were using 320 million units per annum.

22 Dec 1942: White Paper Report on rural electrification by ESB completed.

Rural Electrification Scheme (RES):

1944 Electricity Supply Amendment Bill 1944 (launching the Rural Electrification Scheme).

1945 Electricity Supply Amendment Act passed.

1946: post war: the number of consumers 240,000, using 380 million units per annum. 'urban' consumers, rural dwellings had been virtually untouched.

1946: RES starts (to supply 69% of the rural premises in the State over a ten-year period with government subsidy).

1947: First Rural Electrification Exhibit at the Royal Dublin Society (RDS) Spring Show to demonstrate uses of electricity in the home and on farm.

1957: ESB Simmonscourt Farm at the RDS Spring Show – full model farmyard built to demonstrate electric farm machinery and methods.

1960: RDS Farm Kitchen – full model farmhouse to promote electricity use in the kitchen and home.

1960: over 250,000 consumers connected, completion of original development scheme in sight.

1961: review sent to government. Circa 6000 premises in 17 areas remain, not qualified due to low return, and 100,000 premises unconnected in developed areas.

Post Development Phase (PDP)

1963: The Post Development Phase starts, revisiting already developed areas to connect householders who had not accepted supply or were not economical to serve initially.

31 March 1970: 351,600 rural consumers had been connected.

1976: Electricity (Supply) (Amendment) Bill 1976. in the previous thirty years 420,000 rural houses had been connected - 98% to 99% of all rural houses. Bill proposes to connect final 1,580 premises.

1976: Black Valley connected, one of the last and most remote places in the country to be connected.

Appendix 2 – Domestic technology adoption and gender

Figure A2.1, below, is an example of an advertisement created by the ESB to showcase the value of new domestic technologies available to households with electricity. It specifically highlights the benefits regarding domestic tasks considered “women’s work” at that time, in terms of economic efficiency with low-running costs and high-quality results, as well as independence of tasks from weather conditions.

Figure A2.1: Electricity Supply Board Advertisement entitled "No Work - No Worry", dated 1954.
Source: Electricity Supply Board, 1954, Item MK/PA/5/377: "No Work- No Worry".

Appendix 3 – Trends in ownership of electric appliances

Table A3.1: Domestic appliance ownership (percentage) among rural electricity consumers (1958-1979)

	1958	1964	1966	1968	1973	1979
Main cooking						
- Electric	2	13	15	17	15	25
- Bottled gas	4	14	18	24	33	34
- Solid fuel	84	70	65	57	48	35
- Oil	10	3	2	2	4	6
Water heater	4	5	8	8	8	24
Electric blanket	1	4	7	12	20	35
Food-mixer		2	5	NA	18	38
Hairdryer	1		7	NA	17	48
Electric iron	68	79	82	85	86	87
Electric kettle	39	47	50	53	55	69
Refrigerator	4	8	14	19	44	76
Freezer					4	18
Television		23	43	55	NA	84
Toaster	3	4	5	NA	11	25
Vacuum cleaner	9	10	12	16	21	45
Washing machine	11	19	26	30	41	59

Source: Shiel 1984, p. 166. NA = not available.

Appendix 4 - Changes in the Irish education system during the study period

The 1960s brought about change in Ireland in terms of both the economy and the education system. Export-led economic growth began. During this time the school attendance issue changed – legal sanctions on non-attendance lost importance to social and economic sanctions for not attending school (Fahey 1992), i.e., exclusion from newly developing segments of the labour market. Enrolment at the primary level was 90% by the 1960s, and truancy was now understood in the context of socio-economic status and broader social problems (Fahey 1992). Second, as Ireland tried to open up to the world economy, the education system was reconsidered for its contribution for economic growth (Tussing 1978). The OECD, of which Ireland was a new member, began producing the Investment in Education report, which highlighted the disconnect between the Irish curriculum and skills needed in post-school careers, among other issues. With this in mind, Irish policymakers in education undertook a series of reforms during the 1960s to expand and improve the system.

Important education policy reforms during the 1960s:

1959: Apprenticeship Act – regulation of and increase in number of apprenticeships (affecting the 1963 cohort onward)

1961: Local Authorities Education Scholarships Amendment Act (1961) - scholarships for to secondary schools increase from 500-600 per year to circa 1800 from 1961/1962 and continued rising until 1967.

1962 Vocational Education (Amendment) Act - increased the funding available to vocational education.

1963: Plans announced for Comprehensive Schools and Regional Technical Colleges – not opened until end of study period.

1964: Building grants for Secondary Schools announced.

1965: Plans announced to close most one- and two-teacher National (primary) Schools.

1966: First Comprehensive School opened.

1967: 'Free scheme'; increase building grants for Secondary Schools; Vocational School reform; free school transport scheme.

(Timeline created/adapted from Tussing 1978, O'Sullivan 2012)

Appendix 5 – Mapping electrification areas and timing

The source data for electrification area boundaries and timing of enabling came in two parts:

1. A spreadsheet provided by the ESB Archive that lists areas affected by the Rural Electrification Scheme and the Shannon Scheme and includes a field containing the year electricity was provided to each Rural Scheme area.
2. Scanned images of the Rural Scheme area maps.

Creating a map of the Rural Electrification Scheme area boundaries

1. We created a unique identifier code for all areas listed in the ESB Archive data: PlaceID.
2. We georeferenced and traced Rural Electrification maps from ESB Archive website:
    a. All Rural Electrification map image files from the ESB Archives website were downloaded. Data notes are here: https://esbarchives.ie/2017/09/18/connecting-one-million-irish-homes-to-the-national-grid-1929-1978-note-on-sources/
    b. Used QGIS Georeferencing options to scale each scanned map to match a portion of OSI maps of Ireland from MapGenie Historic - 6Inch Last Edition Black&White 1910s-1950s (ITM). Churches (Ch), Roman Catholic Churches (RCC) and road/river/railway junctions tended to provide the best control points.
    c. The boundary of each area was hand traced from its georeferenced image. These boundaries were checked visually against map features (for example

administrative boundaries, roads, rivers, lakes) where possible and boundaries were adjusted manually where needed.

d. The PlaceID variable was added as an attribute in the Rural Scheme map.
e. One map (Ballycampion) was found to lack a corresponding entry in the ESB Archive spreadsheet, but there was a set of notes for it on the ESB Archive website. This entry was added, yielding a total of 793 Rural Electrification Scheme boundaries. See Figure A5.1.

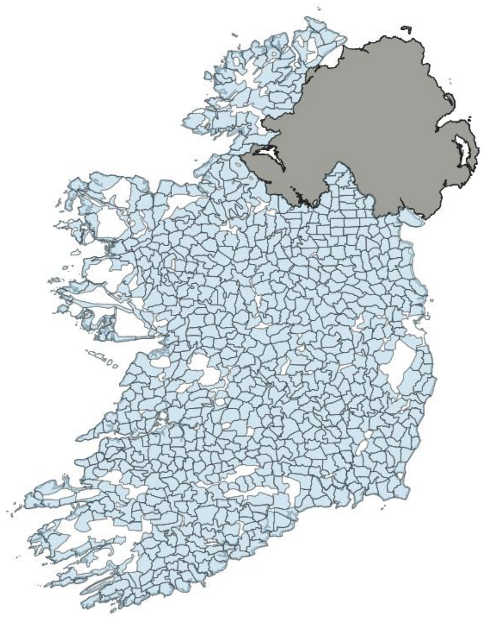

Figure A5.1: Areas covered by Rural Electrification Scheme maps (blue=Rural scheme maps; grey=Northern Ireland)

3. The way the Rural Scheme maps were drawn up, they generally do not include gaps for the towns that were provided with electricity through the Shannon Scheme or earlier. Only a few of the cities and bigger towns do correspond to gaps in the Rural Scheme maps. Since we did not have maps of settlement boundaries from the sample period, we used modern boundaries for settlements and townlands with corresponding names. To map the Shannon Scheme areas, the area name for each entry in the ESB Archive dataset was linked using a database match to the corresponding Settlement and/or Townland in the CSO 2011 Census boundary files. Where a matching Settlement was found (361 entries), that was used, and where there was no matching Settlement a Townland was used (102 entries). Spellings of some names in the ESB Archive spreadsheet needed to be corrected, and a few needed to be translated to or from Irish.
A subset of Settlements and Townlands corresponded to gaps in the Rural Scheme map. We assume that these gaps provide a better representation of the areas previously provided with electricity than modern boundaries do. 11 Settlements were redrawn to match these gaps: Athlone, Ballina, Bantry, Boyle, Celbridge, Cork City, Galway, Limerick, Maynooth, Sligo and Tullamore. A 'Dublin Other' polygon was added to cover areas of Dublin for which we do not have Settlement or Townland boundaries, and we removed parts of the Dublin Other polygon that were

overlapped by other Shannon Scheme Settlements. Final Settlements, including Dublin Other: 362. One Townland was redrawn: The Curragh. Final Townlands: 102. Parts of Settlements that were overlapped by Townlands were removed. The final Shannon Scheme Settlement and Townland maps were merged into a set of polygons representing the Shannon Scheme in full. See Figure A5.2.

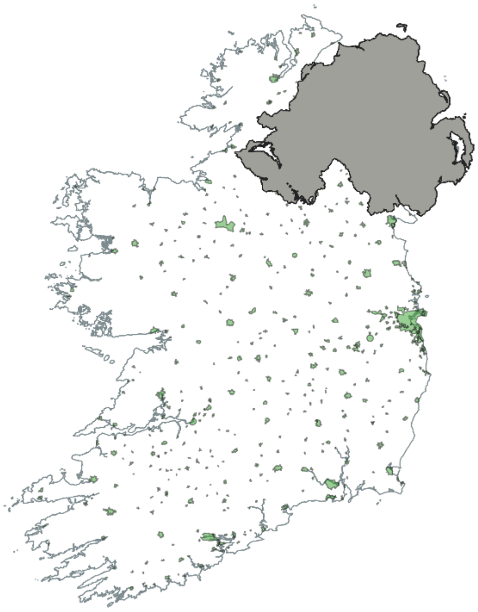

Figure A5.2: Areas covered by Shannon Scheme or earlier electrification projects (green=Shannon scheme; grey=Northern Ireland)

4. A map was created for the Rural Scheme areas omitting the Shannon Scheme areas.
5. Remaining areas of the country not covered by the Rural Scheme or Shannon Scheme were included in a “Not in Schemes” map. This includes 92 polygons, mostly corresponding to mountainous or other lightly populated areas. See Figure A5.3.

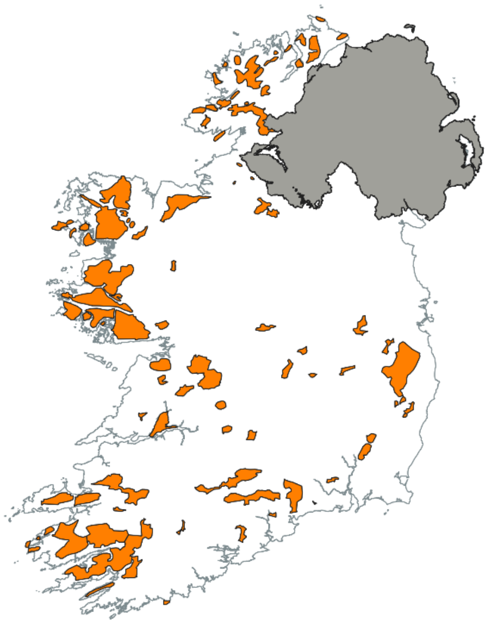

Figure A5.3: Areas not covered by Rural Electrification Scheme or Shannon Scheme (orange=not covered in schemes; grey=Northern Ireland)

Appendix 6 – Mapping electricity transmission distance instrument

To create an instrument for the timing of electrification across all areas, we estimated the distance from the boundary of each area to the nearest 10kV transformer station on the transmission grid in 1938. The map showing these stations was taken from the 1937/38 annual report and is shown in Figure A6.1.

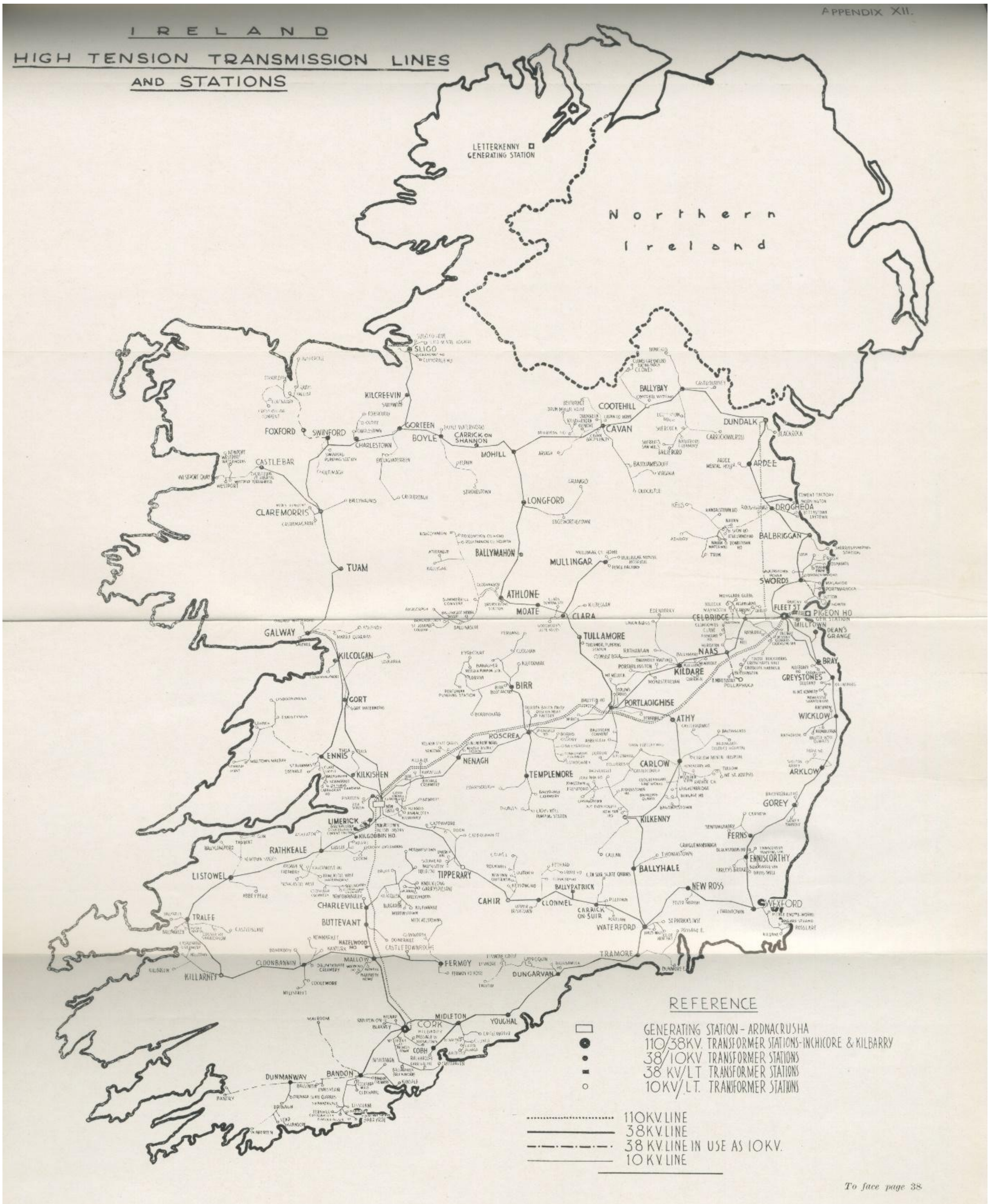

Figure A6.1: Map of electricity transmission links and nodes in Ireland, 1938. Source: Electricity Supply Board , 1938, Appendix XII.

Because the map was not drawn to precisely to scale and thus georeferencing was not practicable, we used the names of the localities with transformers listed on the map to identify the points where this type of infrastructure could be found.[7] For example, a

[7] The concordance table is available on request from the authors.

transformer station in Claremorris was assumed to be at the centroid of the locality named Claremorris. Where two or more transformer stations were listed as being in the same locality, we assume they were located together at the centroid. We have no way to test these assumptions; however, given that most listed localities are not very large, we do not think imprecision about the location of transformer stations within locality boundaries would make a significant difference to the distances we are trying to measure.

Appendix 7 – Panel OLS fixed effects regression results

For comparison with the two-stage least square panel regression results shown in the paper, Table A7.1 provides regression results for a panel OLS model with fixed effects.

Table A7.1: Enrolment intensity regression results; panel OLS with fixed effects, separate models for girls' and boys' school catchments

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
Electrification share	-0.00103	0.00243	0.00203	0.00235
Time	0.000193	0.000264	7.60e-05	0.000231
$Time^2$	3.46e-05	5.64e-06***	2.08e-05	5.24e-06***
Ln(Valuation per capita)	0.0311	0.0193	0.0489	0.0177***
Ln(Population density)	0.00228	0.0169	0.0536	0.0173***
Constant	-0.0255	0.0199	0.0528	0.0204**
Observations	1,995		1,680	
R-squared	0.711		0.659	
Number of catchments	133		112	

Appendix 8: Regression results including correction for spatial confounding, based on adaptation of the gSEM approach with variables replaced by residuals from univariate regressions on spatial spline and Markov Random Field smooths

We adapt the code provided as supplementary material by Dupont *et al*. (2022) to apply a form of gSEM in a context with 2SLS regression including school catchment fixed effects. There are three steps to estimation, which is carried out in R:

1. The catchment-level average over time for each variable in our models is regressed individually on a spatial smooth to capture the pattern of spatial dependence for the variable. Two smooths are used in this step, separately, and both with a k of 40:
    a. Spatial splines constructed using latitude and longitude of school catchments,; and
    b. Markov Random Fields applied to the school catchment boundaries.
2. Residuals from the spatial regression in step 1 are used in the first stage of a 2SLS regression explaining the electrification share in each year as a function of time trends, interactions between time and our candidate instruments, and the other explanatory variables described in the paper.

3. The predicted values for electrification share from step 2 are used to model school enrolment intensity.

Table A8.1 shows some diagnostic tests for the spline regressions and the remaining tables show the full regression results for steps 2 and 3. None of the k-index values is significant, which is consistent with the k value being sufficiently high. All smooth terms are significant apart from the enrolment intensity regression for boys' catchments. The results suggest that boys' enrolments exhibited less pronounced spatial structure on this measure than girls' enrolments (deviance explained: 24.1% for girls, 14.2% for boys).

Table A8.1: Diagnostic tests from univariate regressions of all variables on spatial splines

Variables	Approx. significance of smooth term s(long,lat)			Basis dimension	
	edf	Ref. df	F	k'	k-index
Girls' catchments					
Enrolment intensity	10.1	14.2	2.01**	39	1.05
Electrification share	6.04	8.59	8.12***	39	1.01
Ln(Pop. density)	18.2	24.4	3.23***	39	1.15
Ln(Valuation per capita)	21.4	28.0	11.2***	39	1.08
TRI	33.1	37.5	15.2***	39	1.08
Transmission distance	29.9	35.6	13.1***	39	1.1
Boys' catchments					
Enrolment intensity	5.83	8.27	1.52	39	1.16
Electrification share	2	2.0	27.4***	39	1.09
Ln(Pop. density)	12.3	17.1	2.97***	39	1.07
Ln(Valuation per capita)	15.1	20.7	10.2***	39	1.06
TRI	30.4	35.9	14.6***	39	1.12
Transmission distance	33.1	37.5	24.3***	39	1.32

Table A8.2: Ruggedness instrument, IV instrument regression results with all variables replaced by residuals from spatial spline and MRF regressions

Spatial spline smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
First stage (electrification share)				
Time	0.0700	0.0023***	0.0679	0.0024***
$Time^2$	-0.00104	9.61E-05***	-0.000968	0.000101***
TRI*Time	-0.0128	0.00244***	-0.0133	0.00267***
TRI*$Time^2$	0.000482	0.00011***	0.0005	0.000119***
Ln(Valuation per capita)	-0.742	0.139***	-0.771	0.159***
Ln(Population density)	-1.28	0.121***	-1.35	0.143***
Constant	-0.557	0.0275***	-0.684	0.0314***
Second stage (enrolment intensity)				
Electrification share, stage 1 pred.	0.00523	0.00693	0.0250	0.00646***
Time	-0.000246	0.000507	-0.0015	0.000429***
$Time^2$	4.11E-05	8.94E-06***	4.30E-05	6.44E-06***
Ln(Valuation per capita)	0.0357	0.00822***	0.067	0.0103***
Ln(Population density)	0.00997	0.00998	0.0836	0.0127***
Constant	-0.00734	0.00413*	0.00330	0.00503

MRF smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
First stage (electrification share)				
Time	0.0698	0.00233***	0.0673	0.00241***
$Time^2$	-0.00104	0.0000966***	-0.000968	0.000101***
TRI*Time	-0.00892	0.00217***	-0.0109	0.00225***
TRI*$Time^2$	0.000344	0.0000989***	0.000389	0.000101***
Ln(Valuation per capita)	-0.71	0.145***	-0.714	0.161***
Ln(Population density)	-1.24	0.128***	-1.33	0.145***
Constant	-0.535	0.0282***	-0.711	0.0358***
Second stage (enrolment intensity)				
Electrification share, stage 1 pred.	0.00785	0.00995	0.0239	0.00539***
Time	-0.000431	0.000717	-0.00142	0.000371***
$Time^2$	0.0000438	0.0000116***	0.0000419	0.00000602***
Ln(Valuation per capita)	0.0376	0.0100***	0.0661	0.00963***
Ln(Population density)	0.0132	0.0134	0.0822	0.0110***
Constant	-0.007	0.00563	0.00731	0.00452

Table A8.3: Distance to transmission instrument, IV instrument regression results with all variables replaced by residuals from spatial spline and MRF regressions

Spatial spline smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
First stage (electrification share)				
Time	0.0703	0.00232***	0.0683	0.00243***
Time^2	-0.00104	9.73E-05***	-0.000966	0.000102***
Distance to transmission*Time	-0.00032	0.00139	-0.00171	0.00191
Distance to transmission*Time^2	2.52E-05	6.05E-05	4.36E-05	8.28E-05
Ln(Valuation per capita)	-0.745	0.147***	-0.784	0.168***
Ln(Population density)	-1.23	0.13***	-1.31	0.154***
Constant	-0.549	0.0275***	-0.739	0.0275***
Second stage (enrolment intensity)				
Electrification share, stage 1 pred.	-0.0757	0.0472	0.0105	0.0128
Time	0.00544	0.00333	-0.000502	0.000871
Time^2	-4.27E-05	4.95E-05	2.89E-05	1.30E-05**
Ln(Valuation per capita)	-0.0241	0.0356	0.0555	0.0125***
Ln(Population density)	-0.0896	0.0581	0.0647	0.0183***
Constant	-0.0518	0.026**	-0.00751	0.0095

MRF smooth

Variables	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
First stage (electrification share)				
Time	0.0702	0.00233***	0.0681	0.00242***
Time^2	-0.00104	0.0000973***	-0.000966	0.000102***
Distance to transmission*Time	-0.00117	0.00107	-0.00181	0.00154
Distance to transmission*Time^2	0.0000473	0.0000461	0.0000335	0.0000662
Ln(Valuation per capita)	-0.734	0.147***	-0.768	0.166***
Ln(Population density)	-1.23	0.13***	-1.3	0.151***
Constant	-0.538	0.0283***	-0.768	0.0324***
Second stage (enrolment intensity)				
Electrification share, stage 1 pred.	0.0826	0.0356**	0.0401	0.00804***
Time	-0.00568	0.00249**	-0.00252	0.000553***
Time^2	0.000121	0.0000365***	0.0000575	0.00000857***
Ln(Valuation per capita)	0.0929	0.0273***	0.0788	0.0107***
Ln(Population density)	0.105	0.0441**	0.103	0.0139***
Constant	0.0332	0.0192	0.0198	0.00654***

Appendix 9 – Results adjusted for spatial autocorrelation and autoregression

We extend the base 2SLS fixed effects models to check for effects of spatial dependence using traditional spatial econometrics techniques. Table A9.1 shows the electrification share coefficients for models allowing for spatial autoregression or autocorrelation, using both adjacency and inverse distance matrices. In common with the results of the regressions shown in Online Appendix 8, the distance to transmission parameters were not significant in explaining electrification share after adjustments were made for spatial dependence. This test therefore focuses on the ruggedness instruments.

Table A9.1: Electrification share coefficients from 2SLS regressions of enrolment intensity, second stage, separate models for girls' and boys' school catchments, using ruggedness instrument

Estimators and spatial weights matrices	Girls		Boys	
	Coef.	Robust SE	Coef.	Robust SE
Spatial lag, inverse distance	-0.00930	0.00447**	0.00793	0.00356**
Spatial lag, contiguity	0.0108	0.00386***	0.0130	0.00374***
Spatial autocorrelation, inverse distance	0.0123	0.00425***	0.0210	0.00406***
Spatial autocorrelation, contiguity	0.0112	0.00440**	0.0211	0.00419***

*** p<0.01, ** p<0.05, * p<0.1

Appendix 10 – First destinations for children leaving secondary school without a qualification

There is little direct evidence on the outside options available to children at completion of primary school, but a survey reported in the 1965 *Investment in Education* report shows that boys and girls who started junior cycle of secondary school but did not complete a qualification went to different distributions of first destinations. See Table A10.1.

Table A10.1: Details of 'Left full time Education' in Table 6.3 [Non-examinees from Secondary school junior cycle] Reproduced from Table 6.4 in O'Donoghue et al. (1965).

Destination	Boys %	Girls %
Family farm	35.8	15.6
Family business	9.8	8.6
Total family employment	45.6	24.2
Non-family employment	37.7	59.1
Not at work and other	7.3	11.9
Unaccounted for	9.4	4.8
Total	100	100
Total left full-time education (N)	2,179	2,052